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TECHNICAL APPENDICES B & C

B Hydrogeology Technical Report
C Faulting and Seismicity Technical Report

Environmental Impact Statement &
Environmental Impact Report
for the proposed

Mesquite Regional Landfill

Imperial County, California

SCH. No. 92051024
BLM No. CA-060-02-5440-10-B026

Prepared by the
Bureau of Land Management
California Desert District

and the
County of Imperial
Planning & Building Department

Environmental Consultant
The Butler Roach Group, Inc.
San Diego, California

April 1994

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TECHNICAL APPENDICES

B HYDROGEOLOGY TECHNICAL REPORT

C FAULTING AND SEISMICITY REPORT

ENVIRONMENTAL IMPACT STATEMENT ENVIRONMENTAL IMPACT REPORT

for the proposed

MESQUITE REGIONAL LANDFILL

IMPERIAL COUNTY, CALIFORNIA

SCH. No. 92051024
BLM No. CA-060-02-5440-10-B026

prepared for

BUREAU OF LAND MANAGEMENT
California Desert District
1661 S. 4th Street
El Centro, California

and

COUNTY OF IMPERIAL
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El Centro, California

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APPENDIX B

HYDROGEOLOGY TECHNICAL REPORT

DECEMBER 1993

91-296

HYDROGEOLOGIC ASSESSMENT REPORT MESQUITE REGIONAL LANDFILL

December 1993

ENVIRONMENTAL SOLUTIONS, INC.

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1.0 INTRODUCTION

1. Gold Fields Mining Co. (Gold Fields), Western Waste Industries, and SP Environmental Systems have formed a partnership to develop the proposed Mesquite Regional Landfill, a new Class III (nonhazardous waste) landfill in Imperial County. Arid Operations Inc., a wholly-owned subsidiary of Gold Fields, is the applicant for the proposed landfill and would operate the landfill for the partnership. Gold Fields operated the Mesquite Gold Mine, at the same location, from 1985 until mid-1993 when gold mining operations were taken over by Santa Fe Pacific Minerals Corporation. The Mesquite Regional Landfill (Figure 1.1) is proposed for the long-term disposal of municipal solid waste (MSW) from the populated (e.g., Los Angeles County) portions of southern California. The material disposed would be the residue after recyclables have been removed in the area of the MSW origin. The resulting MSW residue would be nonhazardous solids delivered to the site by a rail-haul system. The landfill is expected to have sufficient volume for disposal of about 600 million tons of MSW residue over an approximate 100-year period.

2. The purpose of this report is to describe the hydrogeologic conditions at the proposed landfill site in sufficient detail for: (1) completion of the environmental analysis to satisfy California Environmental Quality Act (CEQA) and National Environmental Policy Act (NEPA) requirements; and (2) as background information for the Report of Waste Discharge to be submitted to the Colorado River Regional Water Quality Control Board (RWQCB), and the Report of Disposal Site Information (RDSI) to be submitted to the California Integrated Waste Management Board (CIWMB). The information is presented in the following chapters:

   - 2.0 - Background
   - 3.0 - Summary of Investigations
   - 4.0 - Climatic Conditions
   - 5.0 - Hydrogeologic Characteristics
   - 6.0 - Potential Environmental Consequences
   - 7.0 - References

   Also, the following appendices are provided:

   - Appendix A - Mesquite Mine WDO No. 89-034
   - Appendix B - Excerpts from USGS Studies
   - Appendix C - Geophysical Data
   - Appendix D - Gold Fields' Production and Monitoring Well Logs
   - Appendix E - Ground Water Level Elevations
   - Appendix F - Landfill Boring Logs
   - Appendix G - HELP Model Calculations
   - Appendix H - Analysis of Triple Composite Liner Performance
   - Appendix I - GW-1 Pumping Test Results

2.0 BACKGROUND

2.1 GENERAL

1. A unique aspect of the proposed regional landfill is its siting, most of which is on property used by the Mesquite Gold Mine (Figure 2.1). The Mesquite Mine is the largest heap leach gold mine in California, which started operations in 1985. Mining activities are expected to continue for an additional 10 to 15 years. Gold is removed by the process of leaching with a dilute cyanide solution at heap leach pads which will ultimately cover up to 600 to 1,000 acres.

2. The heap leach process is operated in compliance with Waste Discharge Order (WDO) No. 89 034 (Appendix A), issued by the Colorado River RWQCB in Palm Desert, California. The initial heap leach pads were lined with a low permeability flexible membrane liner (FML). Current pads are using a composite liner consisting of FML and clay obtained from mine overburden. These systems prevent the loss of solution impregnated with gold and the threat of ground water contamination. The process solution is collected in a series of lined ditches, enclosed pipes, and ponds. Ground water and vadose zone conditions at the site have been monitored since 1985 in compliance with RWQCB requirements.

3. The WDO provides for the heap leach ore material to be abandoned as nonhazardous mining wastes when analyses of the material show that remaining cyanide concentrations are very low so that water quality would not be threatened. If required, the leach piles will be rinsed with freshwater to achieve the abandonment criteria.

4. The landfill would not be located in the existing or future mine pits. Instead, it would be constructed above the existing desert floor, to maintain a large separation above ground water. The western end of the landfill (Figure 2.2) would extend about 1,400 feet west of the existing mine limits. It is possible to build the landfill in this configuration because of the availability of mine overburden and abandoned spent ore for cover soil materials. Physical testing (e.g., proctor compaction testing, Atterberg limits, and grain size distribution curves) of these materials has shown that they would perform well for this purpose. At completion of mining, approximately 300- and 100-million tons of overburden and ore residue, respectively, would be available.

5. The depth to ground water along the western boundary varies from about 140 to 350 feet (from north to south). Excavation for the landfill in this area would be limited to about 5 feet, only to remove thin lenses of gravel resources, and to grade the area to drain. The eastern

edge of the landfill would extend across the area being used for mine heap leaching, where the depth to ground water is on the order of 200 to 250 feet. It is expected that the landfill base in the eastern portion of landfill would be near the existing ground surface at the bottom of the heap leach pads. An excavation up to 50 feet deep could be made at the eastern landfill area, however, if existing soil or clay in that area is needed for landfill liner construction or closure. Under any circumstances, the depth to ground water would always be maintained at least 150 feet below the base of the landfill.

6. The landfill base would be developed into a series of segments as illustrated in Figure 2.3. This arrangement provides for the following:
   - Leachate collection and recovery systems (LCRS) to be separately monitored for each segment.
   - Efficient management of surface water runoff from infrequent desert storms during the expansion of each new segment area.
   - "Closure" of portions of the landfill as the facility is gradually expanded.

   The cross section in Figure 2.4 illustrates how the ultimate landfill configuration would be constructed continuously above the base segments. It is anticipated that final closure construction would occur as disposal at each individual area is completed.

7. The water supply for the landfill operation would be obtained from the existing large capacity wells used to supply the Mesquite Mine. The "Gold Fields" well field is located several miles south of the mine and landfill (see Section 3.5). This distance was required to reach a large area-wide alluvial aquifer which does not exist beneath the mine or landfill areas. Ground water at the site is limited to small production rates because the area is underlain by low permeability rock. Chapter 3.0 describes a variety of investigations undertaken by Gold Fields since 1982 to evaluate both onsite areas and the remote well field area for development of a water supply.

8. The combination of Mesquite Mine and landfill water usages would not exceed the existing maximum permitted annual well field withdrawal rate of 4,033 acre-feet per year. The most probable actual water use during this time would be 1,500 acre-feet per year, to a high value of 3,000 acre-feet per year when both facilities are operating at maximum water use. After mine closure, water usage would drop to about 1,000 acre-feet per year unless the MSW residue is conditioned with moisture to enhance landfill gas (LFG) generation. In that event, the existing 4,033 acre-feet per year allowance would be continued.

2.2 GROUND WATER PROTECTION SYSTEMS

2.2.1 GENERAL

1. The primary ground water protection systems consist of the following three elements:
   - A LCRS and low permeability liner system at the landfill to prevent downward migration of liquids or LFG.
   - A vacuum extraction system within the landfill to collect the majority of the generated LFG and to prevent positive gas pressures against the low permeability liner.
   - A series of redundant monitoring systems to provide an early indication if the control systems are not operating as intended, so that appropriate operating response could be made.

   These protection systems are described in the following sections. Secondary activities such as compacting of the MSW residue and the provision of temporary and final covers to prevent infiltration of precipitation into the landfill area not described in detail here.

2.2.2 LCRS AND LOW PERMEABILITY LINER SYSTEM

1. The base liner and leachate management system proposed for the landfill is designed to exceed existing and proposed state and federal regulatory standards for Class III landfill liners. The system would include a triple composite liner with an overlying LCRS that would collect potential leachate from each landfill segment. During the life of the proposed landfill, updated liner configurations may be implemented in response to new technologies and/or regulatory requirements. Approval by all regulatory agencies with jurisdiction over landfill liners would be required before an updated liner configuration could be implemented by the Applicant.

2. The liner and LCRS system would consist of the following components, starting at the ground level and going upward (see Figure 2.5):
   - A compacted subgrade prepared with compacted weathered claystone or screened soil for liner placement.
   - A triple composite low permeability liner that would be highly resistant to gas or liquid penetration. This triple liner would include the following components from bottom to top:
     - A Very Low Density Polyethylene (VLDPE), or equivalent FML. The thickness of this FML layer will meet or exceed the 30 mil thickness required for Resource Conservation and Recovery Act (RCRA) Subtitle D double-composite systems.
     - A 1-foot thick layer of compacted clay with properties which will provide a permeability of 10^{-6} centimeters per second (cm/sec).
     - A 60-mil High Density Polyethylene (HDPE) FML above the clay.

- An LCRS consisting of a 1-foot layer of gravel and perforated leachate collection pipes, installed directly above the triple composite liner. The LCRS would provide a free drainage path for any leachate that may form in the landfill, without the potential of creating a large water pressure on the underlying triple composite liner. A 16-ounce geotextile would be provided below the LCRS layer to prevent the HDPE from being punctured. An 8-ounce geotextile would be placed above the LCRS to filter any particles carried with leachate.
- An operations layer (at least 2 feet of soil) to protect the LCRS and triple composite liner from landfill operations.

3. In addition to providing redundant protection against potential leakage, the FML layers would prevent the loss of moisture from the clay which could result in desiccation cracking over the long term. In order for a leak to occur through this triple composite system, there would have to be a defect in both FMLs and a crack in the clay at approximately the same location. The probability of such an occurrence, especially with a high level of quality control, would be extremely low. The estimated performance for this system is discussed in Section 6.3 and Appendix H.

4. The liner installed in each segment would slope toward the southwest, causing any leachate generated to migrate toward the southwest. As the leachate migrates to the southwest, it would be collected in the perforated pipes and conveyed by pipe out from under the landfill footprint for treatment at an onsite water reclamation facility, if required, for recycling or dust control, etc.

2.2.3 LFG CONTROL SYSTEM

1. The triple composite liner discussed above will also be a barrier against the potential migration of LFG generated from the MSW residue. The primary procedures for controlling LFG, however, will be through the installation of horizontal vacuum wells into the MSW as the landfill is developed. Appendix H discusses how this system would be designed to maintain a vacuum above the liner so that there is no pressure trying to push the LFG downward.

2.2.4 MONITORING SYSTEMS

1. Several redundant ground water protection monitoring systems would be incorporated into the landfill design and operation to provide an early warning if any of the primary control systems was not functioning as anticipated. These would include the following monitoring systems, shown in Figures 2.6 and 2.7:

   - Vacuum probes at the top of the operations layer to assure that the LFG control system is functioning adequately (Figures 2.6 and 2.7).
   - The vadose leachate collection layer (with additional liner), beneath the triple composite liner, at zones with highest potential for flow (Figure 2.6) to act as the leachate vadose zone monitor.
   - A series of gas monitoring probes in the vadose (unsaturated) zone beneath the landfill (Figure 2.7).
   - Perimeter vadose zone gas monitoring probes (Figure 2.7).
   - At least one downgradient ground water monitoring well for the initial MSW residue disposal segments (Figure 2.7).

   A vacuum would be drawn on the vadose and perimeter zone probes periodically to determine if there is evidence of leachate or LFG escaping from the containment. If any indication of an escape is observed, the affected area would be covered with a low permeability intermediate cover to minimize infiltration of the air above the landfill and to allow an increase in the vacuum applied. The gas control systems would be enhanced to assure that a negative pressure is maintained above the liner to positively prevent downward gas migration.

2. If, after several years of experience, it is demonstrated that the potential for long-term leachate does not exist in the site's arid environment, a request may be made to the RWQCB to eliminate the second leachate collection layer along the two boundaries and downgradient corner of future segments, and/or to reduce the number of vadose wells required per segment. That request would be made only if monitoring results confirmed that leachate was not occurring after the first several lifts of MSW residue and soil cover were placed in the first segment area, and that a vacuum condition was being maintained above the liner.

2.3 GEOLOGIC SETTING

1. This section is summarized from a detailed discussion of geology and faulting discussed in the Draft Faulting and Seismicity Report for the Mesquite Regional Landfill (Environmental Solutions, Inc. 1992a). The information is provided as background for the detailed site description and ground water information presented in the remainder of this report.

2.3.1 REGIONAL GEOLOGY

1. The proposed project is located at the eastern margin of the Colorado Desert physiographic province near its boundary with the Mojave Desert Province to the east (Figure 2.8). The region is characterized by structural trends expressed as northwest-trending mountain ranges separated by valleys. The dominant feature in the area is the Salton Trough, a large northwest/southeast-trending depression that extends from near Palm Springs to the head of the Gulf of California in Mexico.

2. The floor of the Salton Trough and the gently sloping coalescing piedmont fans at the trough margins are part of the Colorado Desert Province. The mountains east of the Salton Trough, including the Chocolate, Cargo Muchacho, Picacho, and Palo Verde mountains, are part of the Mojave Desert Province (California Division of Water Resources, 1952). The proposed landfill site is located at the upper margin of the piedmont fan and is characterized by a gently sloping (average of about 80 feet per mile) alluvial surface.

3. Figure 2.9 shows a regional geologic map for Imperial County. The Chocolate Mountains reach a maximum elevation of about 2,400 feet at Mount Barrow, about seven miles north of the project area. The mountains are composed of Precambrian to Mesozoic age basement rocks. These are overlain by Tertiary and Quaternary age nonmarine sediments and volcanic units which are exposed in the foothills. The materials comprising the outcrops near the project area are similar to the units exposed in the mountains and foothills to the north.

4. The piedmont fan extending southwestward from the site area is a gently sloping alluvial surface underlain at shallow depth by a pediment (eroded rock surface). Exposed units comprising the alluvial surface consist of three different ages, differentiated according to the degree of dissection and the development of pedogenic soils. The topography slopes toward the southwest and, other than the presence of an intricate braided network of shallow incised channels, is relatively featureless. The gently sloping surface terminates at the Algodones Dunes, about 6 miles southwest of the project site.

2.3.2 TECTONIC SETTING

1. The site lies several miles east of the eastern Salton Trough boundary. This large trough formed as a result of crustal spreading between the North American and Pacific Tectonic plates along the San Andreas Fault System. During Pliocene time (2 to 12 million years ago), Baja California rifted from the mainland of Mexico along what is now the Gulf of California.

Spreading progressed northward into the Salton Trough from the gulf, resulting in the widening and elongation of Imperial Valley. Large horizontal displacements (transverse faulting) along the San Andreas Fault System, now oblique to the Gulf Trend, formed the eastern boundary of the Salton Trough. As the gulf and Salton Trough continued to open, a thick sequence of sediments were deposited which initiated subsistence along block faults at the flanks of Imperial Valley. Tectonic activity continues today as spreading continues in the trough area. This activity is primarily associated with fault systems 26 or more miles from the proposed landfill site.

2. The region represents a transitional zone where coastal rifting processes have joined with transform faulting to develop deep valleys surrounded by high mountains. The mountains have provided a source for sediments that accumulated in the sunken crustal block of the Salton Trough.

2.3.3 SITE GEOLOGY

1. A total of four lithologic units, plus very recent alluvium, have been defined near the proposed landfill. From youngest to oldest, these units include (Figure 2.10):
   - Intermediate alluvium (Qil)
   - Older alluvium (Qtol)
   - The Bear Canyon Conglomerate bedrock unit (Tbc)
   - Undifferentiated metamorphic and igneous basement rocks (bc)

2. The very recent alluvium unit is of Holocene age (less than 10,000 years old) and is constrained to the active channel floors. It consists of unconsolidated sands and gravels with a generally low silt fraction. The intermediate alluvial unit is represented by a sequence of perched alluvial fan surfaces that lie up to 4 feet above the active channels. The intermediate alluvium is slightly coarser grained than the younger recent alluvium, being composed of poorly consolidated sand, gravel and silt that has undergone slight weathering. A moderately-developed desert pavement and desert varnish have formed on the detritus. The weathered surface of the intermediate alluvium ranges between late Pleistocene and early Holocene age (8,000 to 17,000 years old) (Shlemon, 1993). The third alluvial unit, the old alluvium, is represented by the highest alluvial fan surfaces, which are perched up to 8 or more feet above the intermediate age alluvial surfaces. This old alluvium unit is very conspicuous and widespread with a distinct yellowish red color. The old alluvium consists of poorly consolidated sands and gravels that are slightly indurated and weathered. The old alluvium surface displays a very continuous and well-developed desert varnish and desert pavement

(patina), and well-developed desert soil horizons. The old alluvium surface is of late Pleistocene age (35,000 to 40,000 years old) (Shlemon, 1980 and 1993; and Christenson and Purcell, 1985), having undergone at least one pluvial cycle. Beneath the surface soil the old alluvium is estimated to be 60,000 to 70,000 years of age (Oxygen-Isotope Stage 3).

3. All three alluvial units were deposited as fanglomerates derived locally from the Chocolate Mountains. The maximum alluvial thickness overlying the bedrock and basement rock pediment is judged to be about 20 feet, though it varies due to an uneven buried bedrock surface. Lacustrine (lake) deposits associated with the recent Salton Sea, or ancient Lake Cahuilla that previously occupied the Imperial Valley Floor, inclusive of the old shorelines, lie far to the west of the site area and below an elevation of 100 feet.

4. Below the alluvium is a bedrock unit known as the Bear Canyon Conglomerate. This unit is exposed in three isolated outcrops (Figure 2.10) in the north-central portion of the project site as well as in the mine pits to the north. Section views of this unit are shown in Figure 2.11. The Miocene-Pliocene age Bear Canyon Conglomerate consists primarily of massive beds of conglomerate, breccia, sandstone and siltstone. Clasts within the formation consist of granitic and gneissic rocks with a subordinate constituent of volcanics. Interlayered with the nonmarine sediments are vesicular olivine basaltic lava flows that are distinctly dark gray, very hard and range up to about 10 feet thick. Weathering is slight and the beds are slightly to moderately well-cemented with calcium carbonate and/or a clayey matrix. Formational thickness is judged to be at least 1,000 feet. Exposure in the Vista Mine Pit to the northeast of the proposed landfill site indicates that in the site area, the lower 100 (plus) feet consists of bedded lacustrine claystone.

5. The alluvial units and Bear Canyon conglomerate are underlain by Pre-tertiary Age (greater than 65 million years old) igneous and metamorphic rocks which generally consist of biotite and hornblend gneisses, muscovite schist and pegmatite dikes. Foliation in the metamorphic members is well developed, and in outcrop this unit is fresh to moderately weathered. At the surface, the rock appears to be highly fractured and jointed. At depth these discontinuities become fewer in number and tighter, due to confinement by the overlying units. Within the proposed landfill area, depth to basement rock varies from zero at small outcrops to depths in excess of 1,000 feet.

6. Flanking the western side of the Chocolate Mountains is a broad low relief pediment surface that gently slopes from the foot of the range to the floor of the Salton Trough. Within the

site area, a thin mantle of alluvial outwash debris overlies bedrock composed of nonmarine sediments and older metamorphic rocks. The buried basement rock surface was deeply eroded as the mountain front receded. Prior to the formation of this pediment, the Bear Canyon Conglomerate was deposited adjacent to the mountain front. Preceding and accompanying this time period, faulting occurred breaking the terrain up into discrete fault blocks with distinct rock types (Tosdal, et al., 1991).

3.0 SUMMARY OF INVESTIGATIONS

3.1 INTRODUCTION

1. Because of the existence of the Mesquite Mine, the proposed landfill site area is one of the most extensively investigated areas in the California Desert. This chapter summarizes pertinent information from key geological, geotechnical, and ground water evaluations performed for: (1) the Mesquite Mine; (2) the proposed landfill; and (3) other projects in the general vicinity. References to appendices or original documents are provided where appropriate.

2. Figure 3.1 shows the locations of wells in the general vicinity of the site area which are discussed in this report. Figure 3.2 shows the locations of borings and wells in the immediate site area which are used to assist in interpreting subsurface and ground water conditions. Table 3.1 provides a summary of information from selected wells.

3.2 USGS BACKGROUND STUDIES

1. The United States Geologic Survey (USGS) performed the following two investigations in the area which provide important background information for understanding ground water conditions in the Imperial Valley, including those in the general site vicinity:
   - Preliminary Appraisal of Ground Water in Storage, with Reference to Geothermal Resources in the Imperial Valley Area, California (Dutcher, 1972).
   - Geohydrologic Reconnaissance of the Imperial Valley, California (Loeltz, 1975).

   Excerpts from these references discussed in later portions of this report are provided in Appendix B. Of particular interest is Figure 13 of Appendix B.1 which shows the ground water contours of shallow aquifer systems in Imperial and Mexicali valleys for 1962 and 1964. These data show that, in general, ground water flow conditions in southeastern Imperial County traditionally occurred toward the northwest, with the Salton Sea acting as the ultimate "collection sink." The collected water evaporates from the sea and then reenters the hydrologic cycle. Locally, conditions may vary from the contours shown due to pumping, basin boundaries, canal infiltration, etc. However, the figure is useful for illustrating the general baseline ground water flow characteristics of the area.

3.3 INITIAL MESQUITE MINE GROUND WATER SUPPLY EVALUATION

1. Leroy Crandall and Associates (1982) performed an initial ground water supply evaluation for Gold Fields. That investigation considered only a 90-square mile portion of the Amos Basin (Figure 3.3), assuming the only source of recharge to the basin to be from precipitation, with no subsurface inflow from adjacent areas. The study did not recognize the continuity of the Amos, Ogilby, and possibly the East Mesa basins, which is presently believed to exist. The most useful data in that report is the inventory of wells in the vicinity which existed at that time.

3.4 INVESTIGATIONS CONDUCTED BY GOLD FIELDS

1. Since 1981, Gold Fields has drilled several thousand exploration borings in the vicinity of the proposed landfill project. Most of these have been in the Mesquite Mine pit areas, but many were also drilled in adjacent areas to define the limits of mineralization and to verify that gold ore does not occur beneath overburden piles and process facilities (e.g., heap leach pad areas). These holes typically extended to depths of 200 to 400 feet, with some extending to 2,000 feet. Most holes encountered basement rock, which is the host formation for the gold content. Detailed geologic logs of near surface materials were not prepared for exploration borings. However, depth of basement rock was always logged, when encountered. Also, the potential existence of ground water was usually noted when the driller observed cuttings which appeared to be more moist than usual. Exploration borings used for this hydrogeologic investigation are shown in Figure 3.2.

2. Gold Fields also conducted several geophysical surveys in the area to assist in locating shallow basement rock and areas which had the highest potential for mineralization. Appendix C presents gravity and resistivity data obtained during these surveys. The gravity and resistivity data correlate well between each other and with subsurface conditions encountered in boreholes. In general, the data indicates that the mine leach pads and the proposed landfill are both situated in an area north of a high basement rock "ridge." This condition places the facilities in the subbasin area, outside of the main alluvial basin. For purposes of describing the hydrologic system in the vicinity, the area above the basement high is called the "subbasin," while the high volume water-producing basin several miles to the south of the site is considered to be the "main alluvial basin." This terminology is used throughout this report.

3.5 DEVELOPMENT OF THE MESQUITE MINE GROUND WATER SUPPLY

1. Eight potential supply wells were drilled during development of the Mesquite Mine project water supply, and an additional nine were completed for monitoring conditions at the heap leach facilities and well field. These wells are shown in Figure 3.1 and their characteristics are summarized in Table 3.1. This section summarizes the various ground water development activities.

3.5.1 PILOT HEAP LEACH FACILITY AND EXPLORATORY WATER SUPPLY WELLS

1. The first attempt at a water supply well at the Mesquite Mine was Well WT-1 drilled in the initial mine pit area. That well was unsuccessful and yielded only 4 gpm. The second attempt was Well WT-2 which successfully supplied the Mesquite pilot heap leach test facility. Well WT-2 was drilled to a depth of 442 feet and completed in October 1982. The well was rated at 28 gallons per minute (gpm) for short-term uses and produced from basement rock in the initial mine pit area.

2. Two other wells, SM-63 and SM-241, were also completed in the initial mine pit area. These wells supplied water for exploratory drilling. Both of these wells were rated at about 10 gpm and are no longer in use.

3. In March of 1983, Well MCR-80 was drilled as the first attempt to develop a large supply well for the full-scale mining project. It was completed to a depth of greater than 1,000 feet, with over 600 feet of perforations below the static water level. This well was located about one mile east of the leach pad area and was unsuccessful. The water level was completely drawn down at a pumping rate of about 30 gpm. Robert Fox was requested to review pumping test data from this well and in 1985 provided a letter (Fox, 1985a) to Gold Fields concluding that the well is capable of pumping 20 gpm for as long as 48 hours. He recommended that the well not be pumped continuously.

3.5.2 INITIAL IDENTIFICATION OF CURRENT MESQUITE MINE WELL FIELD

1. Fox was initially retained in 1983 as the project's ground water hydrology consultant. Fox (1984a) postulated that in order to be successful, production wells would have to be located about five miles south of the project near the Old Vista Well (see Figure 3.1). This would avoid the high rock zone (subbasin) closer to the mine, where wells were not productive.

2. Fox (1984b) made estimates of recharge and storage considering only the Amos ground water basin (Figure 3.3), without consideration of the potential for recharge from adjacent basins. He concluded that precipitation infiltration at the Sand Hills area would be about 3,500 acre-feet per year, on the order of the maximum 4,033 acre-foot per year requirement estimated by Gold Fields to operate the mine. He concluded that recharge does not occur in the other desert portions of the basin.

3. The initial Gold Fields production well GF-1 was drilled to a depth of 822 feet near the Old Vista Well (Figure 3.2). The log for GF-1 is provided in Appendix D. Water was encountered at a depth of 490 feet. A pump test conducted under the direction of Fox (1985b) indicated a sustained yield of at least 2,600 gpm (4,193 acre-feet per year) with a drawdown of about 54 feet at this well. In 1985, Fox recommended a sustained yield of 1,900 gpm from this well.

3.5.3 ALBIREO LTD. GEOPHYSICAL SURVEYS

1. In 1984, Gold Fields retained Albireo Ltd. to conduct geophysical surveys of the subbasin and alluvial basin areas to better define the basin boundary (Albireo, 1984). The suite of geophysical surveys included resistivity, gravity, self-potential (SP), aeromagnetics and seismic refraction. Data from the gravity and seismic surveys are illustrated in Figures 3.4 and 3.5.

2. The main interpretations from these surveys were: (1) the deep alluvium in the proposed well field area should be productive; and (2) there appeared to be a significant change in subsurface conditions between the proposed well field (main basin area) and the mine site area (subbasin). That change has subsequently been defined by exploration borehole drilling, and explains how the site area is separated from the main alluvial basin.

3. The seismic survey data also provides wave velocities for the various materials, which can be used to estimate their physical properties. The seismic velocities were on the order of 2,000, 7,000, and 11,000 feet per second (fps) for alluvium, conglomerate, and basement rock materials, respectively.

3.5.4 REEVALUATION OF THE BASIN LIMITS

1. Results of the pump test of GF-1 provided a strong indication that the area in which that well was located was capable of producing the large quantities of water required for the Mesquite

Mine project. To further evaluate the basin conditions and to select locations for proposed observation wells and additional production wells, re-evaluation of the hydrology of the Amos Basin was performed by Environmental Solutions, Inc. This supplementary investigation and evaluation focused mainly on storage volume and recharge of the basin based on data from the prior USGS studies (see Section 3.2).

2. Although this evaluation showed that the Amos Basin was originally defined as a separate basin by the California Department of Public Works, Division of Water Resources (1952), its limits were not well defined. At that time, separation of the Amos Basin from the adjacent Ogilby Basin to the south was based on ground water usage rather than on geologic or hydrologic factors (St. Clair Research Systems, 1984c). A more recent designation (California Department of Public Works Water Resources, 1964) incorporates both the Amos and Ogilby Basins into one combined, 600-square-mile Amos/Ogilby Hydrologic Unit.

3. Data from the USGS (1972 and 1975) confirm that the production well field is in the combined Amos/Ogilby basins. That data also indicates that these areas probably are also hydraulically continuous with the East Mesa basin (Figure 3.3). This larger alluvial area receives recharge primarily from the Colorado River and All American Canal, at a rate many times greater than Fox's estimate of about 3,500 acre-feet per year (which accounted only for rainfall infiltration at the Sand Hills). Also, the total available storage is much larger than Fox's initial conservative estimate, which considered only the Amos Basin.

4. Evaluations of the impacts of water extraction for the proposed landfill discussed in Section 5.2 consider the following two possible basin configurations:
    - The most probable configuration which includes the Amos/Ogilby and East Mesa areas.
    - The minimum potential basin by considering that the East Mesa area is not hydraulically connected, possibly because of a buried fault that has been postulated in the Sand Hills area.

3.5.5 COMPLETION OF THE WELL FIELD

1. After re-evaluation of the available data, Gold Fields' well field was developed with completion of two additional production wells (GF-2 and GF-3A) and three observation wells (MGH-1, MGH-2 and MGH-3) near the previously drilled GF-1 (Figure 3.1). Pumping tests of the additional production wells (Fox 1985b) showed similar capacities as for GF-1 (e.g., 1,900 gpm for GF-2), further confirming the high yield potential of the main alluvial

aquifer. Fox estimated transmissivity values from the well field area varying from about 62,700 to 557,000 gpd/ft. The lowest value is used as the basis for conservatively estimating drawdown effects at the well field, as described in Section 6.2.

2. Drilling logs of the additional wells in the production well field (Appendix D) consistently indicated the existence of fine-grained lenses of clayey and silty material in the 350- to 700-foot depth range. It appears that this condition may provide some degree of local confinement above the producing aquifer. In general, however, the alluvial basin consists of an unconfined aquifer.

3.6 SERGENT, HAUSKINS & BECKWITH GEOTECHNICAL INVESTIGATIONS

1. Sergent, Hauskins & Beckwith (SHB, 1984a and 1984b) was retained by Gold Fields to perform two investigations. The first investigation was a general geotechnical investigation for the Mesquite Mine site which included:
    - Geologic and seismic conditions needed to establish design criteria.
    - Evaluation of ground water conditions as they might affect or be affected by the mining and process facility.
    - Laboratory testing of alternative liner systems for the mining heap leach pads.
    - Calculation of rates of seepage through the unsaturated (vadose) zone in the event any leakage could occur during the anticipated operating period.
    - In-place permeability tests conducted in near-surface materials.

2. The borings drilled by SHB for this activity ranged from 13 to 50 feet in depth and are shown as SHB1-1 through -17 in Figure 3.2. Test pits also were excavated and are shown as TP-1 through -5. The pits typically hit "refusal" at 4 to 10 feet of depth.

3. The main conclusions from the SHB investigations pertinent to this hydrogeologic investigation were:
    - Materials encountered in borings and trenches were variably cemented and indurated alluvium.
    - Average permeability of the shallow alluvial materials encountered was about 6×10^{-4} cm/sec. Test results indicated permeability decreased with depth.
    - Ground water under the leach pad area is about 200 to 300 feet deep.
    - Even if any seepage could occur through the liner, ground water would not be threatened because 115 to 580 years of continuous leaching would be required for percolation to reach ground water depth.
    - Permeability of basement rock is low, estimated to be less than 5×10^{-6} cm/sec.

- Ground water in the basement rock is minor and inflow to the entire main mine pit should be less than 22 gpm, (about 0.004 gpm/ft of mine length) even through excavation would occur to a depth of about 200 feet below the original water table.

4. The second SHB (1984b) investigation was conducted primarily to gain information relative to mining and process structures. This program included the borings shown as SHB2-1 through -19 in Figure 3.2. The depth of these borings ranged from 12 to 80 feet.

5. One deeper boring (SHB-20B) was also drilled to a depth of 422 feet in the heap leach pad area. That boring was drilled using a reverse air rotary drilling rig which did not permit collection of "undisturbed" samples. The material for the entire depth was interpreted to be highly stratified, variably cemented alluvium. As discussed in Section 3.7, it is now known that the majority of the SHB-20B boring actually encountered the Bear Canyon Conglomerate.

6. The major conclusions from the deep boring were that basement rock at that location is deeper than 422 feet and ground water was encountered at a depth of 310 feet. Also, the material from the surface to ground water included clayey zones which would retard downward movement of fluids and cause horizontal "spreading" of any percolation which might occur.

3.7 REEVALUATION OF EXISTING SUBSURFACE DATA

1. Small outcrops of material classified as variably cemented alluvium were found to be extensive as they were exposed in excavations during the construction phase of the Mesquite Mine project. In light of these exposures, the existing subsurface data regarding the thickness of alluvium in the site area were re-evaluated by Environmental Solutions, Inc. in 1985. This evaluation included: a more accurate mapping of the top surface of the basement rock, including the buried basement high areas to the west and southwest of the leach pad area; and the occurrence of the Bear Canyon Conglomerate which was mapped at a number of exposed hills in the area by Dillon (1975).

2. The previously identified basement highs mapped as shown in Figure 3.6, based primarily on mine exploration boring data throughout the area, supported previously discussed geophysical information. Review of the existing exploration boring data also involved compilation of ground water elevations observed during drilling as discussed in Section 3.4. Selected ground water level data is summarized in Appendix E.

3. The reevaluation showed that the Bear Canyon Conglomerate bedrock should be expected to occur at shallow depths throughout the mining heap leach pad (and the proposed landfill) area. This formation had been misidentified as alluvium in prior drilling which used air rotary methods that broke up the conglomerate cementation prior to sample recovery. To verify existence of the conglomerate, the continuously cored Boring ESI-1 was drilled by Environmental Solutions, Inc. at the southern end of the leach pad area and at the southwest corner of the proposed location of the Mesquite Regional Landfill (see Figures 2.1, 2.2, and 3.2). The conglomerate was determined to be present from a depth of 12 feet to the total extent of the boring at 250 feet. The log for this boring is provided in Appendix F.

4. Approximately 97 percent core recovery was achieved to the total depth of ESI-1, and the minimum recovery for any 5-foot core barrel in the conglomerate was equal to or exceeded 90 percent. Other characteristics of the conglomerate determined from observations at the core were:
   - The conglomerate contains few fractures.
   - Approximately 50 percent of the cores were logged to have a silt or clay matrix, indicating low permeability conditions.
   - Conglomerate is dense, well consolidated.

5. To further document permeability results, packer testing was also performed on ESI-1. The results of the packer tests are summarized in Table 3.2. For the shallowest depths, the pressure used exceeded the overburden weight of the formation and some hydrofracturing may have occurred.

6. The three tests conducted with pressure below geostatic conditions were 56 to 61, 80 to 85, and 98.5 to 103.5 foot depths. The calculated horizontal permeability for the first two depths is about 3 x 10^{-5} and 2 x 10^{-6} cm/sec, respectively. No measurable flow occurred at the 98.5 foot depth indicating a much lower permeability (e.g., less than 10^{-7} cm/sec). This tendency for decreasing permeability with depth is common for rock as the effects of weathering and microfracturing decrease with distance below the ground surface.

7. A final point regarding the permeability is that packer testing primarily provides a measurement of horizontal permeability. In a stratified geologic environment such as the conglomerate, the vertical permeability is normally much less than horizontal permeability.

3.8 MESQUITE MINE LEACH PAD MONITORING WELLS

1. Six monitoring wells at the Mesquite Mine site have been drilled specifically for ground water monitoring. GW-1, -2, -3, -5 and -6 are located hydraulically downgradient of leach pads and solution ponds. GW-4 is located upgradient of the leach pad area. Conditions at each of these wells are discussed below and lithological logs are provided in Appendix F.

2. Total depth of GW-1 was 430 feet, and ground water stabilized at a depth of about 310 feet. The drilling log indicates that about 30 feet of alluvium was penetrated, followed by about 70 feet of Bear Canyon Conglomerate. Basement rock was encountered at a depth of 100 feet.

3. Both GW-2 and GW-3 were drilled to a depth of 310 feet. Drilling logs indicate Bear Canyon Conglomerate was present to the total depth of both wells and was overlain by only a thin veneer of alluvium (about 10 feet thick). Water levels in GW-2 and -3 stabilized at depths of about 268 and 213, respectively.

4. GW-4 is located nearer the mine pit area where basement rock is shallower. During drilling, conglomerate was encountered at about 10 feet. Basement rock and ground water were encountered at 35 and 221 feet, respectively. Total depth of GW-4 is 320 feet.

5. Well GW-5 was drilled to a depth of 361 feet and ground water stabilized at 277 feet. The drilling log shows that a 20-foot section of alluvium was encountered, overlying 341 feet of conglomerate. Well GW-6 is located downgradient of the Vista heap leach pad and was drilled to 400 feet. Ground water stabilized at 250 feet. The drilling logs show that 20 feet of alluvium overlies 380 feet of conglomerate.

6. GW-1, -2, and -3 were developed by air lift pumping. GW-1 and -3 appeared to produce a visually estimated 15 gpm and 10 gpm, respectively, although it was not anticipated that these yields could be sustained for an extended period. (Note: Section 3.9.5 describes a pumping test conducted on GW-1 to better quantify the yield potential and hydraulic characteristics of fractured portions of the basement rock.) Well GW-2 was air lifted dry within a few minutes. Well GW-4 was developed by bailing and swabbing, followed by pumping. Well GW-4 produced 2 gpm with 28 feet of drawdown. When pumped at 12 gpm, total drawdown occurred in six minutes.

7. Well GW-5 was developed by bailing and swabbing, following by pumping. Pumping at 2 to 3 gpm caused total drawdown in about 7 minutes. Well GW-6 was developed by air pumping. A discharge of 1 to 2 gpm caused 50 feet of drawdown after 5.5 hours.

3.9 ADDITIONAL LANDFILL MONITORING WELLS AND RELATED TEST RESULTS

3.9.1 GENERAL

1. Between October 1992 and January 1993 additional monitoring wells LGW-1 and -2 (Figure 3.2) were installed at the northwest and southwest corners of the proposed landfill area. These locations supplement the upgradient and downgradient coverage provided by the already existing mine-related monitoring wells GW-1 to GW-6. This program also included the following activities:

   - Drilling of continuously cored borehole ESI-2 adjacent to the southwest corner landfill monitoring well LSW-1. ESI-2 was drilled to further define the competency and fracturing characteristics of the Bear Canyon Conglomerate and the basement rock in the vadose zone.
   - Conduction of packer and falling head permeability tests at 11 depths (from about 10 to 336.5 feet deep) in the ESI-2 boring to evaluate permeabilities of the two rock types.
   - Conduction of a pump test in existing monitoring well GW-1 to provide information about the hydraulic conductivity of the basement rock in a zone which has sufficient fracturing to produce small amounts of ground water.

   The boring and monitoring well descriptions are provided in the following sections:

   - 3.9.2 - Boring ESI-2, including permeability testing
   - 3.9.3 - Landfill Monitoring Well LGW-1
   - 3.9.4 - Landfill Monitoring Well LGW-2
   - 3.9.5 - GW-1 Pumping Test Results

3.9.2 BORING ESI-2

1. Boring ESI-2 was drilled using the bentonite mud rotary drilling method to a depth of 354 feet, near the southwest landfill corner. This depth was estimated to be the approximate depth to ground water in that area. The purposes for the boring were to obtain continuous core samples to evaluate rock characteristics and to perform in-hole packer tests to measure hydraulic properties of the vadose zone materials. The log for Boring ESI-2 is provided in Appendix F.

2. As with Boring ESI-1 (Section 3.7), nearly 100 percent core recovery was achieved for both the 63 feet of Bear Canyon Conglomerate and 279 feet of basement rock penetrated. Important characteristics of the cored boring are:
    - The conglomerate:
        - Is well consolidated and variable indurated, but is sufficiently cemented to allow for very high recovery.
        - Contains very few fractures.
        - Includes numerous zones where the gravel matrix consists of silts or clays, which would make the vertical permeability low in comparison with the horizontal flow potential.
    - The basement rock:
        - Is a competent rock mass.
        - Generally has mineralization or clay filling of fractures.

3. A series of packer tests were conducted in Boring ESI-2 to evaluate permeability of the conglomerate and basement rock, as summarized in Table 3.3. The top packer test spanned the contact of the alluvium and conglomerate, and showed a low permeability of about 2 x 10^{-6} cm/sec. Three additional tests in the conglomerate show permeabilities of 7 x 10^{6} cm/sec at 14 to 19 feet, less than 8 x 10^{-7} cm/sec at 39 to 44 feet, and less than 5 x 10^{-7} at 69 to 74 feet. Three packer tests in the basement rock had no measurable flow, indicating a permeability below 5 x 10^{-7} cm/sec.

4. To further evaluate conditions in the basement rock, four falling head permeability tests (see Table 3.4) were conducted by placing water into the bottom of the hole and measuring its rate of fall. This test has an advantage over the packer test because a greater length of the boring is exposed to potential flow. As shown in Table 3.4, the falling head tests consistently indicated a very low horizontal permeability, on the order of 10^{-8} cm/sec.

3.9.3 LANDFILL MONITORING WELL LGW-1

1. Two holes drilled 23 feet apart, using air rotary techniques, were required to locate sufficient ground water to install a monitoring well at the southwest landfill corner. The first 8.5-inch diameter hole was drilled to a depth of 540 feet without encountering measurable water, which was expected to occur at about 350 feet below the ground surface. This initial hole was left open for two days without a measurable accumulation of water. The hole was then reamed to a diameter of 10 inches and a casing was set to act as a monitoring well in the event water were to accumulate over time. During completion, however, a tremmie pipe became stuck in the hole and the hole was abandoned by grouting.

2. The second hole was drilled nearby to allow completion of the desired long-term monitoring well. Foam was used to assist cutting removal in this hole due to the large annulus of the drill string. Unlike the first hole, water was encountered at this new location. The depth of water first observed during drilling was at 430 feet. A static water level depth of 360 feet was measured after completing the hole to 540 feet.

3. The second hole was completed as Monitoring Well LGW-1 in the southwest corner of the landfill as shown in Figure 3.2. This well will serve as a downgradient monitoring well for the initial landfill cell which is planned to be at the southwest corner of the facility. The lithologic log and completion details for Monitoring Well LGW-1 are shown in Appendix F.

4. The observation of no water at the first hole and small but measurable flow from the second, only 23 feet away, reflects the characteristic of flow conditions which exist within the basement rock. At unfractured portions of the rock, the hydraulic conductivity is extremely small and the rock is essentially nonwater bearing. Minor flow is possible, however, at zones where fractures are not completely filled with clay or secondary mineralization.

3.9.4 LANDFILL MONITORING WELL LGW-2

1. The lithologic log and completion details for an additional monitoring well (LGW-2) at the northwest landfill corner are shown in Appendix F. This air rotary hole was drilled into the Bear Canyon Conglomerate to a total depth of 190 feet. During drilling, ground water was first observed at a depth of about 140 feet, in comparison with the expected depth on the order of 115 to 130 feet.

2. After completion, the depth to water in the monitoring well was measured to be 141.3 feet on November 5, 1992, from the top of casing. This corresponds to a water level elevation of about 390 feet above sea level.

3.9.5 GW-1 PUMPING TEST RESULTS

1. To further evaluate the hydraulic properties of fractured portions of the basement rock, a pumping test was performed at existing monitoring well GW-1. This monitoring well is completed in a zone of basement rock with sufficient open fracturing to allow for the presence of some ground water. The results of the pumping test are provided in Appendix G. The pumping test data indicate a permeability of about 5 x 10^{-5} cm/sec for long-term pumping conditions at this location.

3.10 GROUND WATER CHEMISTRY EVALUATIONS

1. Tables 3.5 and 3.6 summarize chemistry data for wells in the main alluvial valley and the subbasin area, respectively. Ground water in both of these areas is generally unsuitable for drinking or irrigation purposes without treatment. Reverse osmosis treatment is used at the Gold Fields Mine for potable water.

2. The water quality of the private Glamis and Boardman wells in the alluvial valley is of particularly poor quality with very large concentrations of Total Dissolved Solids (TDS) and chloride. This characteristic is probably due to the effects of geothermal water which occurs in the vicinity. Dutcher (1972) shows a known geothermal anomaly to occur at Glamis.

3. Section 5.5 describes an additional program being initiated to provide background chemistry data for additional parameters specifically associated with development of the proposed landfill. These background analyses will include sampling of Monitoring Wells GW-1, -2 and -4, and LGW-1 and -2. Based on ground water contours described in Section 5.2.2, three of these wells (GW-1, -2, and LGW-1 in Figure 3.2) are downgradient from the proposed landfill. GW-4 is upgradient, while LGW-2 is crossgradient at the northwestern corner of the proposed landfill.

3.11 OTHER CURRENT INVESTIGATIONS

1. James M. Montgomery (JMM) is presently conducting a county-wide ground water study to assist Imperial County and the Imperial Irrigation District (IID) for future water resources planning. JMM was requested by the County to comment on an initial draft of this report and the water resource sections of the Mesquite Regional Landfill EIS/EIR. Additional analyses in response to JMM's comments are incorporated in this technical report and the appropriate sections of the EIS/EIR. As noted by JMM, it is anticipated that results of their investigations will be useful for estimating the potential impacts of future ground water programs in the area.

4.0 CLIMATIC CONDITIONS

1. The proposed Mesquite Regional Landfill site is in the low California desert. Temperatures range from a high of about 108° F in July to a low of about 40° F in January.

2. Table 4.1 summarizes rainfall data for three nearby U.S. Weather Bureau stations (El Centro, Blythe) for the 1980 to 1991 period, and for Yuma for the period 1980 to 1992. The table also includes data from a weather station at the Mesquite Mine for 1983 to 1987. Average rainfall in the site area is approximately 3 to 4 inches, and usually varies from about 1 to 7 inches.

3. The evaporation rate in the site area is estimated to be about 100 inches per year (SHB, 1984a). The resulting large evaporation to rainfall ratio results in a condition where infiltration of precipitation to recharge ground water does not generally occur. This condition was verified by measurements of soil moisture content from borings in the site area (SHB, 1984a). That data showed that the existing soil moisture content is below the field moisture capacity. This condition indicates that there presently is no downward migration of water in the vadose zone.

4. It is anticipated that this high evaporation to rainfall ratio would also result in a net moisture extraction condition at the landfill. Therefore, no leachate is expected to be collected once the LCRS (Figure 2.6) is covered with the first 10- to 20-foot lift of MSW residue and daily cover. The only exception might occur if the waste moisture content is conditioned by water addition to enhance trash degradation and energy recovery. In that case, special liner, LCRS and/or monitoring systems would be provided to assure collection without the potential for migration to the otherwise dry vadose zone.

5.0 HYDROGEOLOGIC CHARACTERISTICS

5.1 INTRODUCTION

1. This chapter describes the hydrogeologic conditions which would determine the potential ground water effects of operating the proposed Mesquite Regional Landfill. The descriptions are subdivided to specifically address conditions in the Amos/Ogilby and East Mesa ground water basins, and the small subbasin beneath the proposed landfill site. The discussion is subdivided into the following sections:

   - 5.2 - Ground Water Occurrence
     - 5.2.1 - Amos/Ogilby and East Mesa Basins
     - 5.2.2 - Site Subbasin Area
   - 5.3 - Ground Water Usage
     - 5.3.1 - Amos/Ogilby and East Mesa Basins
     - 5.3.2 - Site Subbasin Area
   - 5.4 - Aquifer Characteristics
     - 5.4.1 - Amos/Ogilby and East Mesa Basins
     - 5.4.2 - Site Subbasin Area
   - 5.5 - Ground Water Quality

5.2 GROUND WATER OCCURRENCE

5.2.1 AMOS/OGILBY AND EAST MESA BASINS

1. The hydrogeologic unit tapped by the existing Mesquite Mine well field (and proposed landfill well field), shown in Figure 3.3 is believed to include the Amos/Ogilby and East Mesa hydrogeologic areas. The overall size of this area is about 860 square miles within Imperial County, although the pervious alluvium containing the stored ground water extends for hundreds of additional square miles southward into Mexico. The western edge of the combined area is formed by much finer-grained sediments in the agricultural portion of Imperial County.

2. As a most conservative assumption, it could be hypothesized that there is not strong hydraulic communication between the Amos/Ogilby and East Mesa areas. For this unanticipated case, the size of the alluvial basin which includes the Mesquite Mine well field would be about 300 square miles. Evaluation of the effects of this conservative assumption is discussed at the end of this section.

3. The thickness of the pervious alluvium in the combined Amos/Ogilby and East Mesa areas varies from east to west, extending to maximum depth of 10,000 feet (Appendix B.1,

excerpts from USGS, Dutcher, 1972). The total amount of water stored within this alluvium is estimated to be about 470,000,000 acre-feet (Table 3 in Appendix B.1) although much of the deeper portions of this water has high temperature and total dissolved solids (TDS) conditions. The stored water to a depth of 3,000 feet (where temperatures are consistently below 100° F and TDS values are lower) in the combined basins is estimated by the USGS to be about 229,000,000 acre-feet (Table 4 in Appendix B.1).

4. Local runoff and surface water infiltration recharge to the large alluvial basin is small. Infiltration for most of the area is essentially zero because of the high evaporation to rainfall ratio, and nearly complete utilization of precipitation by plants in the vegetated portions of the area. Very minor amounts of recharge may occur along the mountain slopes, estimated to be on the order of only tens of acre-feet per year per mile, based on ground water flows at the deepest existing Mesquite Mine pit (see Section 5.2.2). The maximum locally-derived recharge may occur at the Sand Hills where precipitation can infiltrate rapidly into the pervious surface materials. Fox (1984b) estimates that recharge at the Sand Hills may be on the order of 3,500 acre-feet per year.

5. Prior to construction at the All American and Coachella canals, the basin was recharged primarily by the Colorado River, mostly as underflow between the Cargo Muchacho Mountains and Pilot Knob (Figure 3.3). The current magnitude of this recharge source, based on: (1) estimates of hydraulic properties of the alluvium (Section 5.4.1); (2) the regional hydraulic gradient; and (3) the width of the flow path; is estimated to be on the order of 20,000 acre-feet per year. Ground water contours indicate that additional Colorado River recharge also occurs to the south, into the Mexican portion of the alluvial basin.

6. The largest sources of recharge to the area have occurred as leakage from canals. The USGS (Loeltz, 1975) estimates that in the late 1960s, leakage from the All American and Coachella Canals was about 100,000 and 130,000 acre-feet per year, respectively. The Coachella Canal was subsequently lined in the early 1980s so that currently recharge is mostly from the All American Canal.

7. Considering all sources, the estimated amount of recharge to the Amos/Ogilby and East Mesa areas is on the order of 100,000 acre-feet per year.

8. For the conservative scenario that the Amos/Ogilby and East Mesa areas are not hydraulically connected, both the available storage and recharge estimates would be lower. For this case, the estimated values are approximately:
   - Storage = 126,000,000 acre-feet.
   - Recharge = 50,000 acre-feet per year.

   The recharge estimate is based on comparison of: (1) the portion of the canal in each area from Figure 13 in Appendix B-1; and (2) the relative proportion of Colorado River derived water estimated for the two areas by the USGS (Table 4 of Appendix B-1).

5.2.2 SITE SUBBASIN AREA

1. Ground water within the subbasin beneath the proposed landfill site is within lower permeability conglomerate bedrock and basement rock (see Section 5.4.2). Pump testing of a number of wells constructed for the Mesquite Mine project in the early 1980s showed that production from individual wells in the subbasin would generally be less than 10 gpm.

2. Figures 5.1 shows a cross section through the subbasin and alluvial basin, and Figure 5.2 shows the estimated depth to ground water at existing wells and exploration borings in the subbasin (see Appendix E). The depth of water beneath the proposed landfill area varies from about 140 feet at the northwest corner to more than 300 feet in the south-central portion of the landfill. Exact depths are available for each well in the area and at exploration holes where water level soundings were taken. Approximate data is also available from logged exploration holes, where the driller indicated that ground water may have been encountered. The depths to water shown as 400 feet in Figure 5.2 are exploration borings where no apparent water was observed during drilling of unfractured portions of the low permeability basement rock. Ground water quantities in these areas of the basement rock are very small.

3. The depths shown compare very favorably with regard to the 5-foot minimum separation requirement between the MSW residue and ground water in California Code of Regulations (CCR) Title 23, Chapter 15. Variations in the depths shown are expected to be very small because of the lack of local infiltration. For example, nearly 10 years of level data for the Mesquite Mine Monitoring Wells (GW-1 to -6) have shown level fluctuations of less than 2 feet, most of which probably is associated with measurement accuracies. Generally, the change in depth has been within tenths of a foot, including the drought of the late 1980s, and the September to May 1992 period when rainfall was more than twice the average year.

4. Figure 5.3 shows ground water contours, estimated from the depth information shown in Figure 5.2. The general ground water gradient within the subbasin is in the northeast to southwest direction, which corresponds to the surface slope of the Chocolate Mountains toward the alluvial basin. General flow is in the direction of the gradient, from northeast to southwest. As illustrated in Figure 5.3, the gradient through the site area is very consistent. None of the many data points indicate anomalous flow conditions.

5. Recharge to the subbasin is expected to occur only at higher elevations on the Chocolate Mountain slopes where basement rock is exposed. The amount of recharge is very small in comparison with that which occurs in the main Amos/Ogilby alluvial aquifer. Using the unit seepage rate of 0.004 gpm per foot into the mine pit estimated by SHB (1984(a)(b), and Section 3.6), the total ground water flow across the landfill site would be on the order of 50 to 100 gpm. This represents a minute percentage of the water stored and recharged to the Amos/Ogilby alluvial basin.

5.3 GROUND WATER USAGE

5.3.1 AMOS/OGILBY AND EAST MESA BASINS

1. Because of the availability of surface water from irrigation canals and the low density land use in eastern Imperial County, relatively little ground water is used. Figure 3.1 shows the location of wells in the area known to be in use. Table 3.1 summarizes the estimated existing yield for those which are used for water supplies.

2. Ground water is also extracted from the portion of the alluvium aquifer in Mexico, especially for agricultural purposes. Although precise information concerning this use is not known, it is estimated that the net extraction rate (extraction minus recharge) could be on the order of 180,000 acre-feet per year. The portion of this agricultural water which reinfiltrates back to ground water is not known.

5.3.2 SITE SUBBASIN AREA

1. There currently are no existing or planned ground water supply wells within the subbasin area. It is unlikely that future wells would be installed in this area because of the limited amount of available water, low yield potential, restrictions on potential land uses, and poor natural water quality with respect to drinking standards. If a future industrial use were to occur (such as the proposed landfill), the water supply would have to be obtained from wells installed in the deep alluvium to the south.

2. Some dewatering pumping does occur in the mine pits as they are excavated below the original ground water surface. The water is used for dust control at the mine. SHB (1984a) estimates long-term inflow when the Big Chief Pit reaches its maximum depth will be approximately 22 gpm. This inflow, after mining is completed and the surrounding ground water reaches equilibrium, is expected to evaporate. Observations in the pit indicate that the inflow observed occurs along fractures in the basement rock. Wide zones between fractures do appear to produce measurable flow.

5.4 AQUIFER CHARACTERISTICS

5.4.1 AMOS/OGILBY AND EAST MESA BASINS

1. Pump test data reported by the USGS (Loeltz, 1975, included as Table 1 in Appendix B.2) show that transmissivities in the alluvial basin are generally high, ranging from 220,000 to 880,000. Values as high as 880,000 gpd/ft were determined for a well near the southeast corner of Imperial County in Sec. 31, TI6S, R20E. The transmissivities generally tend to decrease in the west and north directions. For example:

   - Pump test results for Gold Fields' production wells indicate transmissivity values in the range of 62,700 to 557,000 gpd/ft (Fox, 1985b).
   - A Southern Pacific Company well located near the north end of the sand dunes, used to irrigate trees which provide a windbreak along their tracks, shows a transmissivity between about 47,000 and 62,000 gpd/ft.

   An explanation for this trend is that the alluvium toward the southeast is derived primarily from the Colorado River and, therefore, is more granular. The alluvium closer to the Chocolate Mountains contains more locally derived, finer-grained materials. High yields can be expected from wells throughout the basin, however. For example, each of the three Gold Fields' wells have capacities which exceed 1,900 gpm.

2. The hydraulic conductivities corresponding to the tests conducted by USGS (Loeltz, 1975), range from about 10- to 100-foot per day (3×10^{-3} to 3×10^{-2} cm/sec) for the alluvium. Tests at Gold Fields' supply wells indicate a hydraulic conductivity on the order of 10^{-2} cm/sec (250 gpd/ft^2) as estimated by Fox (1985a).

3. The USGS (Loeltz, 1975) estimates that the storage coefficient for gravels in the alluvial basin can be as high as 0.2 to 0.4. Relatively short pumping tests (e.g., 96 hours) performed at Gold Fields' production Well No. GF-3 indicated a storage coefficient as low as about 0.005, however. This value may indicate a partially confined condition, reflective of the fine granular

layers observed between the depths of 350 to 700 feet in the production wells. This condition is expected to be fairly local and not reflective of long-term aquifer performance. Instead, a storage coefficient of 0.1 is considered for drawdown predictions described in Section 6.2.

5.4.2 SITE SUBBASIN AREA

1. Packer tests conducted in the Bear Canyon Conglomerate in Borings ESI-1 and -2 show a permeability varying from as high as about 0.1 ft/day ($3x10^{-5}$ cm/sec) at shallow depths to less than 0.0003 ft/day (10^{-7} cm/sec at a depth of 98.5 feet) (Section 3.7). This characteristic of decreased permeability is common because effects of weakening and stress relief diminish with depth.

2. Packer and falling head tests in the unfractured portion of basement rock indicates very low permeability conditions (less than 0.0003 ft/day or 10^{-7} cm/sec). This condition correlates well with the experience of exploration geologists who frequently logged deep basement borings as being "dry."

3. The permeability of fractured zones in this basement rock are estimated based on work for the mine pits performed by SHB (1984a) and a recent pump test conducted in Monitoring Well GW-1. Based on data from early, low-capacity Gold Fields wells (see Section 3.6), SHB (1984a) estimated the average permeability for the basement rock to be about 0.015 ft/day (5×10^{-6} cm/sec). This valve was used to estimate a long-term flow rate into the mine pit of 22 gpm. Experience from dewatering of the mine indicates that original estimate is reasonably accurate. The results of the pumping test at GW-1 (see Appendix I) indicates that the yield potential of that well would be on the order of under 20 gpm. This corresponds to a permeability estimate of 0.18 ft/day (6×10^{-5} cm/sec). Long-term flow conditions in fractured portions of the basement rock probably would correspond to an average condition between these two values, on the order of 10^{-5} cm/sec.

5.5 GROUND WATER QUALITY

5.5.1 HISTORICAL MONITORING DATA

1. Tables 3.5 and 3.6 summarize ground water quality data for the alluvial valley and subbasin zones, respectively. The analyses presented include data from: (1) the 1982/86 period for the Mesquite Mine development and permitting; and (2) from 1989/1991 to illustrate that significant changes have not occurred over time.

2. The quality data for the alluvium aquifer also indicates that water from this source is not suitable for drinking without prior treatment. Drinking water standards are exceeded in the alluvium aquifer for chlorine, fluorine, TDS, and specific conductivity. As noted in Section 3.10, Gold Fields Operating Company (GFOC) treats this water by a reverse osmosis process prior to its potable use at the Mesquite Mine.

3. The data for the subbasin area also consistently shows the water quality to be poor, characterized by high values of salinity, TDS, chloride, fluoride, sulfate, and several metals. This water is not suitable as drinking water without prior treatment.

4. Additional conclusions determined from the data in Tables 3.5 and 3.6 are:
   - The Glamis and Boardman wells have the highest concentrations of most parameters and especially specific conductivity, TDS, and chloride. This condition is interpreted to occur because these wells are most affected by natural mixing with geothermal water, associated with the Glamis Known Geothermal Resource Area (KGRA). This condition is also reflected by temperature variations. Temperatures as high as 159° F have been reported for the Glamis well, compared to typical values in the ranges of 93° F and 83° to 86° F in the alluvium and subbasin wells, respectively.
   - Natural chemistry variations are generally greater in subbasin wells than for conditions in the alluvium. This condition may occur because of differences in rock types where the wells are screened.

5.5.2 LANDFILL-RELATED MONITORING DATA

1. As discussed in Section 3.10, baseline monitoring at Wells GW-1, -2 and -4 and LGW-1 and -2 will be expanded during 1993 to obtain appropriate background chemistry for additional constituents which are associated with the potential characteristics of landfill leachate. The additional parameters will be determined by the RWQCB staff and will include at least volatile organic compounds (VOCs) and nitrates. These chemicals often are contained in landfill leachate.

6.0 POTENTIAL ENVIRONMENTAL CONSEQUENCES

6.1 INTRODUCTION

1. Potential environmental consequences to ground water as a result of construction and operation of the Mesquite Regional Landfill would result from either:

   - Effects on water availability in the alluvial basin as a result of extraction of up to 4,033 acre-feet per year of water for operation of the landfill.
   - Contamination of the ground water due to the downward migration of leachate or LFG from the base of the landfill.

   Contamination of ground water due to other sources is not considered to be possible because of provisions to minimize the potential for the escape of potential contaminants. For example, all storage tanks would be constructed above ground, within containment areas, and water treatment facilities would be provided with double containment.

2. Section 6.2 discusses the potential effects of the proposed water extraction on conditions in the alluvial basin and also the nearest existing wells. This section also explains why wells in the alluvial basin cannot cause water level decreases at the landfill which could cause undesirable settlement or subsidence.

3. Section 6.3 explains reasons why there is essentially no threat of ground water contamination from leachate because of arid site conditions, the planned triple composite liner, overlying LCRS and vadose zone monitoring system, and the depth to ground water properties of subsurface materials. This section also identifies the importance for collecting LFG from within the landfill to prevent its migration to ground water.

6.2 GROUND WATER USAGE EFFECTS

1. The proposed landfill project would utilize water from the existing Mesquite Mine water supply wells located south of the project area in the Amos/Ogilby alluvial basin. Even during the remaining 10- to 15-year projected life for the Mesquite Mine, the combined water use from the two projects would not exceed the currently permitted maximum annual withdrawal rate of 4,033 acre-feet. The most probable actual water use during this period is expected to range between the existing mine usage rate of about 1,500 acre-feet per year to 3,000 acre-feet per year when both facilities are operating at maximum water use. The increment between the maximum allowed and the average anticipated use represents a reserve to allow for unusually high evaporation conditions and conditioning of residue at the landfill for methane generation enhancement.

2. Following closure of the mine, the average annual water usage would be expected to be less than 1,000 acre-feet per year, primarily for dust control and for use as make-up water (replacement for evaporated water) for container and equipment washdown facilities. The majority of the washdown water would be reused after treatment at the onsite water reclamation facility. The maximum allowed usage of 4,033 acre-feet per year could be realized if moisture conditioning of the MSW were utilized to enhance energy recovery. Considering the maximum annual water use for the entire proposed 100-year landfill operating life, the total project-related use would represent about 0.2 percent of the 229,000,000 acre-feet of usable and recoverable water estimated to exist within the combined Amos/Ogilby and East Mesa alluvial basins (see Section 3.2). The maximum usage would represent 0.3 percent of the available storage if it is conservatively estimated that the alluvial basins are not connected.

3. The maximum extraction rate represents only about 4 percent of the estimated 100,000 acre-feet of annual recharge which would occur from the Colorado River and the All American Canal to the combined basins, or 8 percent of the 50,000 acre-feet of estimated recharge to just the Amos/Ogilby basin. In either case, the Amos/Ogilby alluvial basin would continue to experience a large net recharge of water. Based on the comparison of the water to be extracted in relationship to the available stored water and the much larger amount of recharge, water usage for the proposed landfill would not have a noticeable effect on the Amos/Ogilby alluvial basin.

4. The localized cone of depression that would form around the well field as extraction continues for the proposed project life would potentially have some effect on the depth of water at the several other wells identified within the general area. These especially include the Boardman and Glamis wells (Figure 3.1) located 3.5 and 5.5 miles from the Mesquite water supply wells, respectively, in the Amos/Ogilby basin.

5. The potential drawdown for The Bureau of Land Management's (BLM's) Cahuilla Ranger Station well located about 12 miles to the west of the well field in the East Mesa basin was also estimated. This estimate assumes that the Amos/Ogilby and East Mesa Basins have strong hydrogeologic communication. If the basins are not connected, the BLM well would not be impacted at all. Noticeable well drawdown conditions would not be expected at the Gold Rock Ranch or American Girl Mine wells which are closer to the large Colorado River and All American Canal recharge zone than to the existing Mesquite Mine well field. Table 6.1 summarizes the amount of drawdown projected at the extraction rates of 1,000 acre-feet per year (projected use for landfill alone, without moisture enhancement) and 4,033 acre-feet per year for up to 100 years in 25-year increments.

6. The drawdown estimates were calculated the following two ways:

   - Using a two-dimensional USGS finite element model (MODFLOW).
   - Using a Theis solution for verification.

   The analysis for both methods considers that the high rock subbasin to the north represents a "no-flow" boundary. This boundary is located 6,000 feet north of the pumping wells and extends 12,000 feet to the west. Then the boundary trends northward to simulate the subbasin configuration shown in Figure 3.3. The following aquifer characteristics and modeling parameters were used:

   - Aquifer Transmissivity = 65,000 gpd/ft.
   - Average Aquifer Thickness = 1,150 feet (to Elevation 1,100 below mean sea level (msl) based on Section B-B' in Figure 2.11).
   - Specific Yield = 0.1.
   - Pumping wells fully penetrate the aquifer.
   - No recharge to the aquifer occurs.
   - The well field pumping rate is 4,033 acre-feet per year.

7. The analyses are considered to be conservative, especially because: (1) the lowest value of transmissivity for the well pumping tests was used; (2) the large amount of recharge (50,000 or 100,000 acre-feet per year as described in Section 3.5.4) was not included; and (3) the aquifer is much deeper than assumed. Therefore, the actual drawdown at each well will be less than that calculated.

8. The Boardman well, being closest to the Mesquite Mine well field, would have the most potential drawdown. If the Mesquite Mine or landfill project wells were pumping at a capacity of 1,000 acre-feet per year, the conservative estimate of drawdown at the Boardman well would be approximately 3 feet after 100 years. For a maximum pumping rate of 4,033 acre-feet per year, the drawdown at the Boardman well with no basin recharge would be about 13 feet. The Glamis well, located 5.5 miles from the Mesquite Mine well field, could have a drawdown between 3 and 12 feet after a 100-year period of continuous production by the Mesquite Mine wells operating between a range of 1,000 and 4,033 acre-feet per year. The conservative estimated drawdown at BLM's Cahuilla Ranger Station well would be 2.6 and 11.1 feet for the same conditions, and assuming that this well is within the same basin as the Gold Fields wells.

9. A comparison of the drawdown estimates for the area wells and the total water column in each (Table 6.1), shows that the potential effect created by the maximum pumping rate for 100 years from the Mesquite Mine wells would be a small percentage of the available water in the affected wells. The conservative maximum estimated drawdown of 13 feet in the

Boardman well represents 3 percent of the 430-foot depth of water in that well; the maximum drawdown of 12 feet at the Glamis well represents 4 percent of the 290-foot depth of water in that well. The 11 feet of maximum drawdown at the Cahuilla Ranger Station well would represent about 6 percent of the 186 feet of water available at that location. These changes would not adversely affect the capacity of these wells to provide relatively small amounts of water required at these locations.

10. Pumping of the alluvial production wells would not have any noticeable effect on water levels in the rock subbasin beneath the landfill. Therefore, there is no potential for subsidence due to dewatering, which could potentially affect landfill liner continuity.

6.3 GROUND WATER QUALITY

6.3.1 INTRODUCTION

1. Potential impacts to ground water quality at the site could occur in several ways:
   - Leakage of stored liquids (e.g., fuels, lubricating oils) containing undesirable constituents into the subsurface.
   - The seepage of leachate from the landfill through the protective liner and through the vadose (unsaturated) zone to the ground water.
   - The migration of LFG from the facility into the unsaturated zone, resulting in the dissolution of trace gases into the underlying ground water.

   Site conditions and the project design would eliminate the potential for ground water contamination to occur due to leakage of stored liquids. The desert climate conditions naturally mitigate against impacts from short-term events because of the small amount of rainfall, high evaporation rate, and the natural moisture conditions in the vadose zone. These conditions indicate that downward migration of rainfall infiltration toward the ground water, which could transport contaminants, is not currently occurring in this desert area. Also, hydrocarbon-type materials (e.g., fuels) would be stored only in aboveground tanks using double-contained systems, with warning devices when appropriate, to provide early warning of any leakages which may occur. The WDO obtained from the RWQCB would also include standard operating requirements to immediately remediate any spills of substantial quantities of hydrocarbons which may occur due to mechanical breakdowns on site equipment, etc.

2. There are, however, potential sources of long-term exposure of the subsurface to liquids or LFG migration which could overcome the natural conditions which restrict downward migration of contaminants. The potential for landfill leachate and LFG migration and ground water quality impacts are discussed in Sections 6.3.2 and 6.3.3.

6.3.2 LEACHATE MIGRATION POTENTIAL

1. Because of the arid conditions at the site, and the high amount of compaction of the waste, it is not anticipated that leachate will be generated, except possibly for very short periods if rainfall occurs at the initial startup period of a disposal cell. After one or two layers of MSW (10 to 20 feet thick each) and related daily cover is placed, precipitation would not be expected to reach the LCRS and landfill liner system. Appendix G provides calculations using EPA's HELP model for 6-inch daily, 12-inch intermediate and 24-inch temporary soil covers. The results show a general net outward migration of moisture. For even an unusually wet year, such as that which occurred during the 1992/1993 rainy period, the amount of infiltration through the daily cover would only be about 6 inches. It is anticipated that this amount of infiltration would be absorbed within the top 2 feet of underlying MSW residue.

2. If for any reason (e.g., moisture conditioning for LFG enhancement), however, a source of leachate were to occur anywhere within the landfill area, and occupy a common location in the leachate collection system for a very long period, the liquid could theoretically represent a potential threat for migration through the vadose zone to the subbasin ground water regime.

3. Appendix H provides data concerning the potential for seepage to occur through the low permeability liner and into the vadose zone, considering hypothetical defects in a synthetic layer portion of the composite liner. This information on liner system performance is developed from Chapter 7 of the *Mine Waste Management Manual* edited by Hutchison and Ellison (1992). Information in that chapter is partly based on the report *Leakage Through Liners Constructed With Geomembranes* prepared by Giraud and Bonaparte (1989) for the U.S. EPA. Appendix H also provides calculations to verify that the LCRS will freely drain leachate without creating a large head on the triple composite liner system.

6.3.3 LFG MIGRATION POTENTIAL

1. Although the proposed landfill would be constructed essentially at or near the existing ground surface, the potential for downward migration of LFG to the depth of ground water in the subbasin could be possible because of the large areal extent of the landfill. For example, the maximum width of the landfill is about 8,000 feet, in comparison with the depth to ground water of 400 or more feet, depending on location. Because of this configuration, there would be the potential for LFG generated in the decomposing trash to migrate to the ground water if special gas control systems are not installed.

2. The landfill design, including the base liner system, would include provisions to collect the majority of the LFG in a manner, and at locations, which would avoid: (1) development of air and methane mixtures which could be explosive; and (2) the transport of trace organics to the atmosphere and/or ground water. The LFG control system would consist of gravel-filled horizontal collector trenches, containing perforated pipes, installed at approximately 50- and 250-foot vertical and horizontal c, respectively. Each perforated pipe would be connected to a vacuum header pipe on the outside of the landfill. The bottom row of pipes, approximately 20-feet above the liner, would be spaced at 125 feet to provide added assurance that a vacuum condition could be maintained at the landfill base. Vacuum applied throughout the landfill would collect and transport generated LFG to a common location for destruction by flaring or for energy recovery usage. The gas control system arrangement could be modified in the future, if appropriate, in response to changing technology.

3. In summary, potential for the downward migration of LFG into the vadose zone would be improbable because vacuum will be maintained within the landfill and directly above the low permeability liner system at the base. Monitoring systems would be incorporated into both the landfill and vadose zone to assure that the vacuum condition is maintained and LFG migration is not occurring.

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TABLE 3.1

SUMMARY OF VICINITY WELLS

	WELL IDENTIFICATION	PURPOSE	RATED YIELD (gpm)	TOTAL DEPTH (ft)	PERFORATED INTERVAL (ft)	SEALED DEPTH (ft)	DATE COMPLETED	APPROXIMATE WATER LEVEL (ft)	
								DEPTH	ELEVATION
Wells Completed in Bedrock or Basement Rock of the Subbasin	WT-2	Production/ Upgradient Monitoring	28	442	154 - 404	N/A	October 1982	185	550
	SM-63	Production	10	477	N/A[1]	N/A	N/A	185	575
	SM-241		10	520				200	560
	Singer Well		15	470				220	575
	GW-1	Downgradient Monitoring Well	Less than 15	430	317 - 416	0 - 291	October 1985	313	277
	GW-2		Less than 10	310	207 - 305	0 - 190		270	360
	GW-3		1 - 2	310	196 - 296	0 - 193		213	437
	GW-4	Upgradient Monitoring Well	2	320	209 - 309	0 - 190	October 1986	223	502
	GW-5	Downgradient Monitoring Well	2	359	259 - 359	0 - 250	October 1988	270	N/A
	GW-6		1 - 2	338	238 - 338	0 - 222	January 1990	250	N/A
	LGW-1	Downgradient Monitoring Well	Less than 10	450	300 - 450	0 - 285	February 1993	357	210
	LGW-2	Upgradient Monitoring Well	Less than 10	190	130 - 190	0 - 130	November 1992	141	490
	MCR-80	Intended for Large-Scale Production but Insufficient Yield	Less than 26	1,017	402 - 1,002	0 - 50	March 1983	197	523
Wells Completed in Amos-Ogilby Basin Alluvium	GF-1	Production	3,000 - 6,000	822	506 - 810	0 - 20	December 1983	474	79
	GF-2		2,300+	908	658 - 885	0 - 50	March 1985	462	78
	GF-3A		2,250+	940	690 - 930	0 - 50	March 1986	469	77
	MBH-1	Observation	N/A	600	510 - 590	0 - 300	November 1984	467	81
	MBH-2			640	510 - 630	0 - 400		470	80
	MBH-3			683	510 - 680	0 - 400		458	79
	Boardman Well	Production	N/A	735	N/A	N/A	1980	309	95
	Glamis Well	Production	300	520	N/A	N/A	1972	235	100
	Cahuilla Ranger Station	Production	50	300	210	N/A	July 1992	114	80[2]
	Gold Rock Ranch Well	Production	N/A	521	N/A	N/A	1935	397	83
	American Girl Mine 26-1	Production	50	N/A	N/A	N/A	N/A	280	119
	American Girl Mine 26-2	Production	400	393	N/A	N/A	August 1988	280	119

91-296 (3/4/94/ds)

(1) N/A = Not available.

(2) Estimated based on approximate ground surface of 195 feet above mean sea level.

TABLE 3.2

BORING ESI-1
PACKER TEST RESULTS

TEST SECTION	DEPTH (ft)		TEST PRESSURE (psi)	STEADY FLOW (gpm)	Q (ft^3/sec)	h_1 (ft)	h_2 (ft)	H (ft)	K	
	FROM	TO							ft/sec	cm/sec
1	16	21	40(1)	0.9	2.0 x 10^{-3}	93.0	18.5	111.5	1.98 x 10^{-6}	6.03 x 10^{-5}
1	16	21	60(1)	1.7	3.79 x 10^{-3}	139.5	18.5	158.0	2.64 x 10^{-6}	8.04 x 10^{-5}
1	16	21	80(1)	2.8	6.24 x 10^{-3}	186.0	18.5	204.5	3.35 x 10^{-6}	1.02 x 10^{-4}
2	20	25	40(1)	1.25	2.78 x 10^{-3}	93.0	22.5	115.5	2.65 x 10^{-6}	8.06 x 10^{-5}
2	20	25	60(1)	2.40	5.35 x 10^{-3}	139.5	22.5	162.0	3.63 x 10^{-6}	1.11 x 10^{-4}
2	20	25	80(1)	2.40	5.35 x 10^{-3}	186.0	22.5	208.5	2.82 x 10^{-6}	8.60 x 10^{-5}
3	26	31	40(1)	1.1	2.45 x 10^{-3}	93.0	28.5	121.5	2.22 x 10^{-6}	1.05 x 10^{-5}
3	26	31	60(1)	1.5	3.34 x 10^{-3}	139.5	28.5	168.0	2.19 x 10^{-6}	6.66 x 10^{-5}
3	26	31	80(1)	2.6	5.79 x 10^{-3}	186.0	28.5	214.5	2.97 x 10^{-6}	9.05 x 10^{-5}
4	56	61	40	0.6	1.34 x 10^{-3}	93.0	58.5	151.5	9.73 x 10^{-7}	2.96 x 10^{-5}
4	56	61	60	1.2	2.67 x 10^{-3}	139.5	58.5	198.0	1.48 x 10^{-6}	4.52 x 10^{-5}
4	56	61	80(1)	1.75	3.90 x 10^{-3}	186.0	58.5	244.5	1.75 x 10^{-6}	5.35 x 10^{-5}
5	65	70	100(1)	2.1	4.68 x 10^{-3}	232.6	67.5	300.1	1.71 x 10^{-6}	5.23 x 10^{-5}
6	80	85	40	0.05	1.11 x 10^{-4}	93.0	82.5	175.5	6.95 x 10^{-8}	2.12 x 10^{-6}
6	80	85	90(1)	4.83	0.0108	209.3	82.5	291.8	4.07 x 10^{-6}	1.24 x 10^{-4}
6	80	85	100(1)	5.09	0.0113	232.6	82.5	315.1	3.94 x 10^{-6}	1.20 x 10^{-4}
7	98.5	103.5	105±	Not Measurable						

91-296 (10/28/93/sh)

(1) These tests were conducted at pressures approaching or exceeding overburden pressure, and may have resulted in hydrofracturing of the tested zone.

TABLE 3.3

BORING ESI-2
PACKER TEST RESULTS

TEST SECTION	DEPTH (ft)		TEST PRESSURE (psi)	STEADY FLOW (gpm)	Q (ft^3/sec)	h_1 (ft)	h_2 (ft)	H (ft)	K	
	FROM	TO							ft/sec	cm/sec
1(1)	9	14	10	1.0×10^{-2}	2.2×10^{-5}	23.1	11.5	34.6	7.0×10^{-8}	2.1×10^{-6}
1(1)	9	14	29(3)	4.0×10^{-1}	8.9×10^{-4}	67.0	11.5	78.5	1.3×10^{-6}	3.8×10^{-5}
1(1)	9	14	41(3)	4.2	9.3×10^{-3}	94.8	11.5	106.3	9.6×10^{-6}	2.9 x 10-4
1(1)	9	14	60(3)(4)	–	–	–	–	–	–	–
2(1)	14	19	11	4.0×10^{-2}	8.9×10^{-5}	25.4	16.5	41.9	2.3×10^{-7}	7.1×10^{-6}
2(1)	14	19	17(3)	1.4×10^{-1}	3.1×10^{-4}	39.3	16.5	55.8	6.1×10^{-7}	1.9×10^{-5}
3(1)	39	44	20	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	46.2	41.5	87.7	$<2.8 \times 10^{-8}$	$<8.4 \times 10^{-7}$
3(1)	39	44	30	1.0×10^{-2}	2.2×10^{-5}	69.3	41.5	110.8	2.2×10^{-8}	6.7×10^{-7}
3(1)	39	44	40(3)	5.0×10^{-2}	1.1×10^{-4}	92.4	41.5	133.9	9.0×10^{-8}	2.8×10^{-6}
4(1)	69	74	32	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	74.0	71.5	145.5	$<1.7 \times 10^{-8}$	$<5.1 \times 10^{-7}$
4(1)	69	74	51	4.0×10^{-2}	8.9×10^{-5}	117.9	71.5	189.4	5.2×10^{-8}	1.6×10^{-6}
4(1)	69	74	66	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	152.5	71.5	224.0	1.1×10^{-8}	3.3×10^{-7}
5(2)	79	84	31	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	71.6	81.5	153.1	$<1.6 \times 10^{-8}$	$<4.8 \times 10^{-7}$
5(2)	79	84	50	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	115.6	81.5	197.1	$<1.2 \times 10^{-8}$	$<3.7 \times 10^{-7}$
5(2)	79	84	70	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	161.8	81.5	243.3	$<1.0 \times 10^{-8}$	$<3.0 \times 10^{-7}$
6(2)	249	254	40(5)	–	–	–	–	–	–	–
6(2)	249	254	89	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	205.7	251.5	457.2	$<5.3 \times 10^{-9}$	$<1.6 \times 10^{-7}$
7(2)	309	314	41	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	94.8	311.5	406.3	$<6.0 \times 10^{-9}$	$<1.8 \times 10^{-7}$
7(2)	309	314	65	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	150.2	311.5	461.7	$<5.2 \times 10^{-9}$	$<1.6 \times 10^{-7}$
7(2)	309	314	91	$<1.0 \times 10^{-2}$	$<2.2 \times 10^{-5}$	210.3	311.5	521.8	$<4.6 \times 10^{-9}$	$<1.4 \times 10^{-7}$

91-296 (3/4/93/ds)

(1) Bear Canyon Conglomerate.
(2) Basement Rock.
(3) These tests were conducted at pressures greater than overburden in order to obtain comparative data with 1985 packer testing.
(4) This test experienced sudden pressure loss, indicating fracturing of formation, and therefore the test results were not used.
(5) This test showed an increase in pressure (rose to 60 psi), and therefore the test results were not used.

TABLE 3.4

BORING ESI-2
FALLING HEAD TEST RESULTS

TEST INTERVAL (ft)	Q (ft^3/min)	Head, (ft) h	Borehole radius, (ft) r	Viscosity at 20°C, (dimensionless) V	K	
					ft/sec	cm/sec
312.5 - 317	2.73×10^{-4}	35.0	0.17	1	3.0×10^{-9}	9.1×10^{-8}
317 - 319	1.26×10^{-4}	29.0	0.17	1	2.0×10^{-9}	5.8×10^{-8}
319 - 325	1.26×10^{-4}	26.5	0.17	1	1.8×10^{-9}	5.7×10^{-8}
325 - 326.5	9.5×10^{-5}	27.5	0.17	1	1.6×10^{-9}	4.9×10^{-8}

91-296 (10/28/93/sh)

TABLE 3.5

ALLUVIAL VALLEY GROUND WATER QUALITY DATA

DRINKING WATER STANDARDS(1)		pH (units)	SC (µmho/cm)	TDS (mg/L)	Cl^- (mg/L)	F^- (mg/L)	SO_4^{2-} (mg/L)	As (mg/L)	Cr (mg/L)	Fe (mg/L)	Mn (mg/L)	Hg (mg/L)
		6.5 - 8.5	900	500*	250*	1.6	250*	0.05	0.05	0.30*	0.05*	0.002
WELL	DATE											
GF-1	8/30/82	6.89	*1,940*(2)	*1,145*	*445*	*1.74*	*261*	0.015	*0.07*	*5.00*	*0.06*	NA
	3/21/83	7.06	*2,150*	*1,084*	*443*	*4.80*	239	0.004	<0.01	*0.36*	0.01	NA
	12/5/83	7.28	*1,900*	*1,216*	*399*	*4.30*	*252*	0.005	0.02	0.13	<0.01	NA
	5/2/84	6.90	*2,150*	*1,178*	*441*	*2.50*	*274*	0.006	<0.01	0.01	0.01	NA
	10/25/85	7.81	*1,779*	*1,162*	*425*	*3.50*	*265*	0.001	0.02	*0.82*	0.01	NA
	12/12/85	7.81	*1,954*	*1,137*	*436*	*2.30*	*266*	0.014	<0.01	*0.53*	<0.01	NA
	5/21/86	7.80	*1,950*	*1,309*	NA	NA	NA	NA	NA	NA	NA	NA
GF-2	4/19/85	8.13	*1,980*	*1,072*	*403*	*1.9*	240	0.004	0.01	0.08	0.01	NA
	4/21/85	8.01	*1,980*	*1,108*	*404*	*2.1*	237	0.004	0.01	0.09	<0.01	NA
	10/25/85	7.68	*1,699*	*1,088*	*404*	*1.6*	*252*	<0.001	<0.01	0.09	*0.09*	NA
	5/21/86	7.60	*1,886*	*1,217*	NA	NA	NA	NA	NA	NA	NA	NA
GF-3A	4/21/86	7.94	*1,643*	*1,069*	*386*	*1.82*	237	0.006	<.01	0.10	<0.01	NA
	7/16/91	8.00	*1,092*	*2,100*	*410*	*2.5*	*250*	<0.001	0.01	0.17	*3.3*	NA
Boardman	2/4/84	7.75	*5,560*	*3,080*	*1,333*	*2.80*	155	0.032	<0.01	*0.37*	*0.05*	NA
Glamis	4/25/72	6.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2/4/84	7.73	*5,490*	*3,046*	*1,371*	*2.81*	168	*0.067*	<0.01	1.1	*0.12*	NA
Gold Rock	1/19/49	NA	NA	*1,510*	*667*	NA	242	NA	NA	NA	NA	NA
	5/20/64	7.7	NA	*1,950*	*897*	*1.8*	*275*	NA	NA	NA	NA	NA
	9/29/68	7.5	NA	*844*	*348*	*1.9*	125	NA	NA	NA	NA	NA

91-296 (11/4/93/pm)

NA = Not Available

(1) California Domestic Water Quality and Monitoring Regulations. California Health and Safety Code and the CAC Title 22.

(2) The numbers typed in italics equal or exceed drinking water quality standards.

* Recommended secondary drinking water standards - upper and short-term levels may be higher.

TABLE 3.6

SUBBASIN AREA GROUND WATER QUALITY DATA

DRINKING WATER STANDARDS (1)		pH (units)	SC (umho/cm)	TDS (mg/L)	Cl^- (mg/L)	F^- (2) (mg/L)	SO_4^{2-} (mg/L)	As (3) (mg/L)	Cr (3) (mg/L)	Fe (3) (mg/L)	Mn (3) (mg/L)	Hg (mg/L)
		6.5-8.5	900	500*	250*	1.6	250*	0.05	0.05	0.30*	0.05*	0.002
WELL	DATE											
WT-2	11-22-82	7.88	*1,650*[4]	*1,000*	142	*2.5*	*262*	0.05	<0.01	*0.80*	*0.08*	---
	3-21-83	7.23	*1,760*	*1,004*	137	*3.1*	*274*	0.014	<0.01	*0.56*	0.03	---
	2-4-84	8.0	*1,660*	*996*	127	*1.6*	*256*	0.031	<0.01	0.03	<0.01	---
	5-4-84	8.4	*1,800*	*997*	146	*1.32*	*251*	---	---	---	---	---
	1-21-85	8.2	---	*1,040*	136	---	*256*	---	---	---	---	---
	10-25-85	7.99	*1,630*	*969*	140	*1.71*	*260*	0.003	<0.01	0.07	*0.07*	---
	12-12-85	8.36	*1,561*	*938*	110	*1.58*	*266*	0.026	<0.01	0.2	0.01	---
SM-63	11-22-82	7.61	*1,560*	*960*	125	1.3	*280*	0.01	<0.01	0.12	0.01	---
	3-21-83	7.14	*1,650*	*992*	104	*3.3*	*274*	0.014	<0.01	*1.00*	0.02	---
Singer	2-4-84	7.85	*2,250*	*1,328*	*286*	*1.6*	*415*	0.005	<0.01	*0.82*	0.06	---
GW-1	10-25-85	7.34	*3,320*	*2,1282,*	*595*	*1.5*	*283*	0.007	*0.08*	*33*	*14*	---
	12-12-85	7.52	*3,105*	*032*	*486*	*1.09*	*168*	0.037	*0.14*	*22*	*1.7*	---
	10-28-86	8.25	*3,081*	*1,819*	*660*	2.2	*360*	*0.075*	0.04	*3.5*	*4.1*	---
	4-92	7.5	---	*1,802*	---	---	---	---	---	---	---	
GW-2	10-25-85	7.35	*3,230*	*1,960*	*876*	*1.7*	*325*	0.001	<0.01	0.19	*0.84*	---
	12-12-85	7.75	*3,485*	*1,992*	*863*	*1.02*	*330*	0.007	<0.01	*0.77*	*0.5*	---
	4-92	7.7	---	*1,645*	---	---	---	---	---	---	---	---
GW-3	10-25-85	7.92	*1,221*	*869*	129	1.3	*297*	0.002	<0.01	0.04	0.04	---
	12-12-85	8.23	*1,346*	*890*	134	*1.81*	*292*	0.017	<0.01	*0.39*	*0.11*	---
	4-92	7.7	---	*1,136*	---	---	---	---	---	---	---	---
GW-4	10-23-86	8.14	*2,027*	*1,270*	*309*	2.0	*342*	0.009	0.03	0.04	*0.14*	0.0009
	4-92	7.7	---	*1,1911,*	---	---	---	---	---	---	---	---
GW-5	6-7-89	8.4	---	*170*	302	*2.5*	229	*0.071*	0.20	0.03	*1.6*	<0.0005
	4-92	9.2	---	*978*	---	---	---	---	---	---	---	---
GW-6	7-30-91	8.0	---	*1,273*	430	*1.2*	*300*	<0.005	<0.005	*32*	*0.21*	<0.0001
MCR 80	1-18-85	7.28	*3,306*	*1,800*	609	---	*425*	---	---	*6.8*	---	---

91-296 (3/4/94/ds)

(1) California Domestic Water Quality and Monitoring Regulations. California Health and Safety Code and the CAC Title 22.
(2) 1.6 mg/L based on annual average air temperature of 73°F.
(3) Data presented as total (mg/L). Soluble (< 0.45µm) level data also available.
(4) The numbers typed in italics equal or exceed drinking water quality standards.

* Recommended secondary drinking water standards. Upper and short-term levels may be higher.
(---) Not available or not applicable.

TABLE 4.1

RAINFALL DATA(1)

YEAR	WEATHER STATION			
	EL CENTRO	BLYTHE	YUMA	MESQUITE MINE
1980	4.35	4.35	2.07	–
1981	3.86	3.24	1.55	–
1982	4.92	5.17	5.46	–
1983	5.50	5.96	5.36	1.47
1984	2.33	6.06	6.19	4.99
1985	4.72	5.07	2.68	5.18
1986	3.91	3.68	1.73	3.17
1987	2.24	3.33	3.67	3.03
1988	2.43	2.93	2.72	–
1989	0.92	1.62	6.75	–
1990	1.97	1.66	1.95	–
1991	3.86(2)	4.32(2)	3.17	
1992	--(3)	--(3)	5.07	–
Average	3.42	3.95	3.72	3.57

91-296 (10/28/93/sh)

-- = Not Available

(1) Data received from National Weather Service unless otherwise indicated.

(2) Data received from Continental Weather Service.

(3) Not yet available.

TABLE 6.1

POTENTIAL DRAWDOWN EFFECTS AT PROJECT AREA WELLS

PUMPING RATE (acre-feet)	LENGTH OF PUMPING (years)	CONSERVATIVE[1] ESTIMATES OF DRAWDOWN IN FEET		
		Boardman Well (3.5 miles from well field. 430-foot water column.)	Glamis Well (5.5 miles from well field. 290-foot water column.)	Cahuilla Ranger Station Well (12 miles from well field. 186-foot water column.)
1,000	25	1.1	0.8	0.5
	50	1.8	1.6	1.3
	75	2.5	2.3	2.0
	100	3.3	3.0	2.6
4,033	25	4.4	3.5	2.3
	50	7.3	6.3	5.1
	75	10.2	9.0	8.0
	100	13.3	12.1	11.1

91-296 (10/28/83/sh)

(1) The estimates are considered to be very conservative because they assume the lowest aquifer hydraulic properties determined from pumping tests at the Gold Fields wells, and that the estimated existing recharge of 50,000 to 100,000 acre-feet per year to the alluvial basin does not occur.

91-296 FS REV. 8/24/92

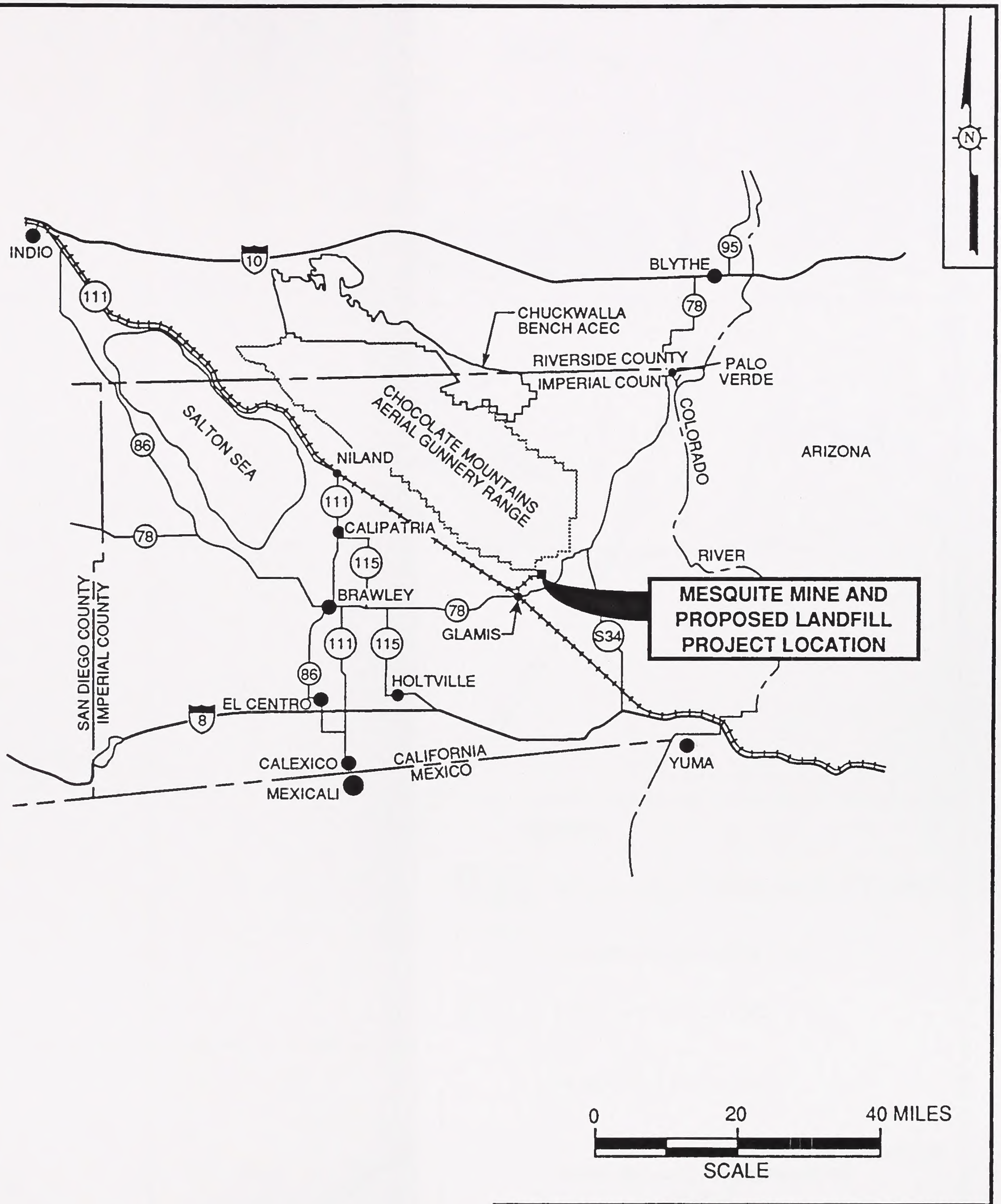


FIGURE 1.1

REGIONAL LOCATION MAP

MESQUITE REGIONAL LANDFILL

91-296HAR-12 REV. 08/31/93

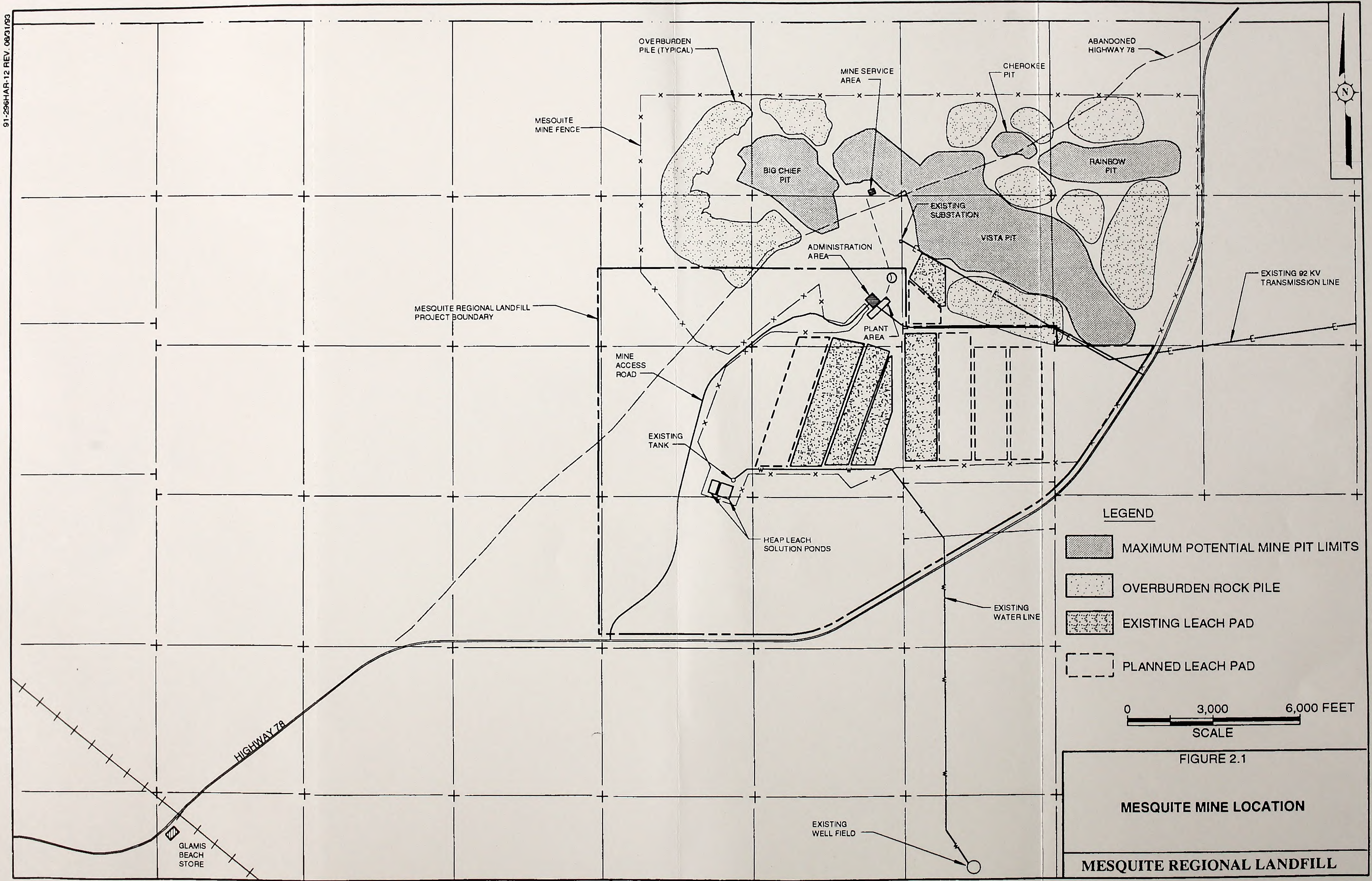


FIGURE 2.1

MESQUITE MINE LOCATION

MESQUITE REGIONAL LANDFILL

91-296HAR-02 REV. 8/31/93

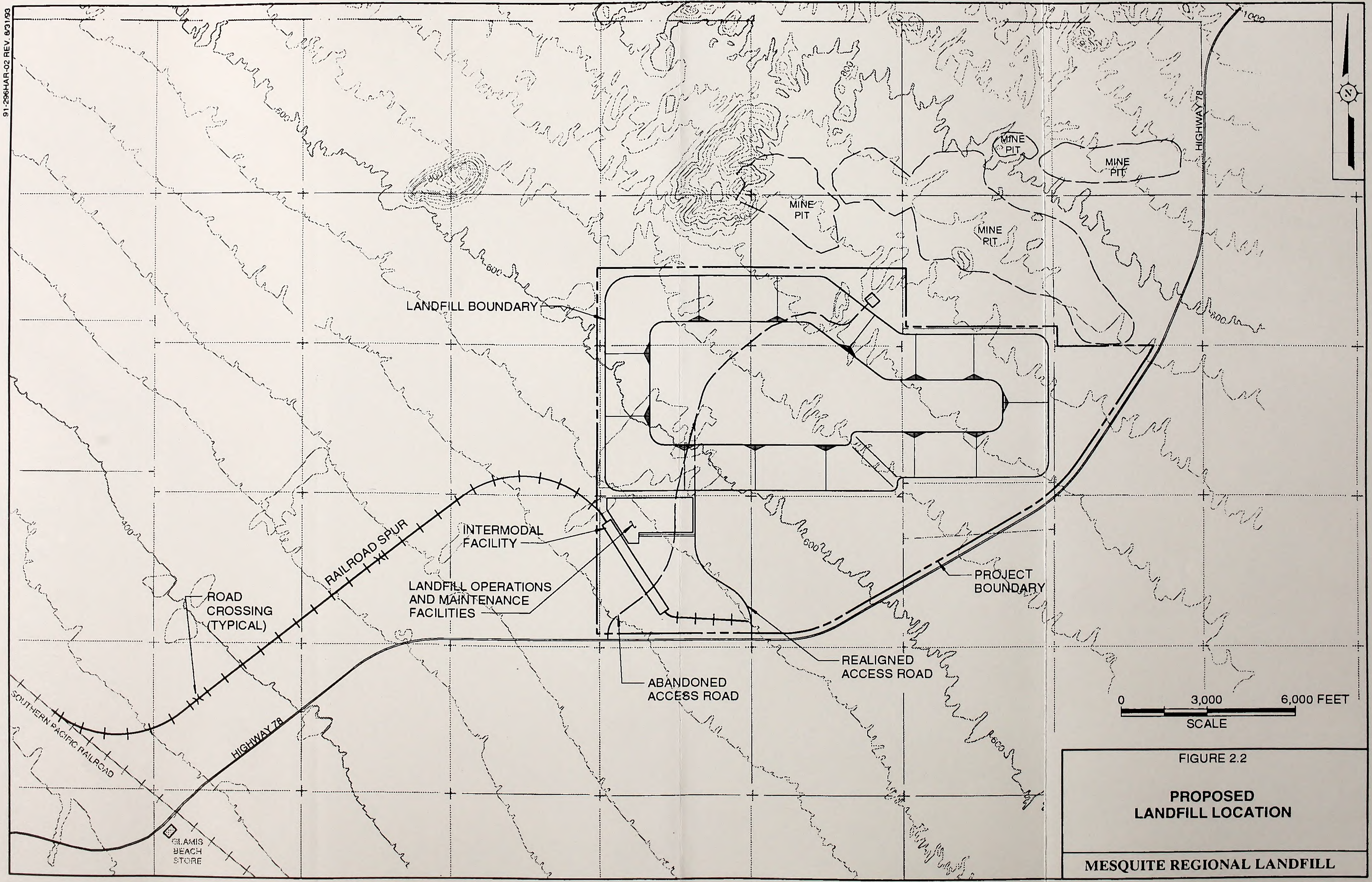


FIGURE 2.2

PROPOSED LANDFILL LOCATION

MESQUITE REGIONAL LANDFILL

91-296HAR-05 REV. 8/31/93

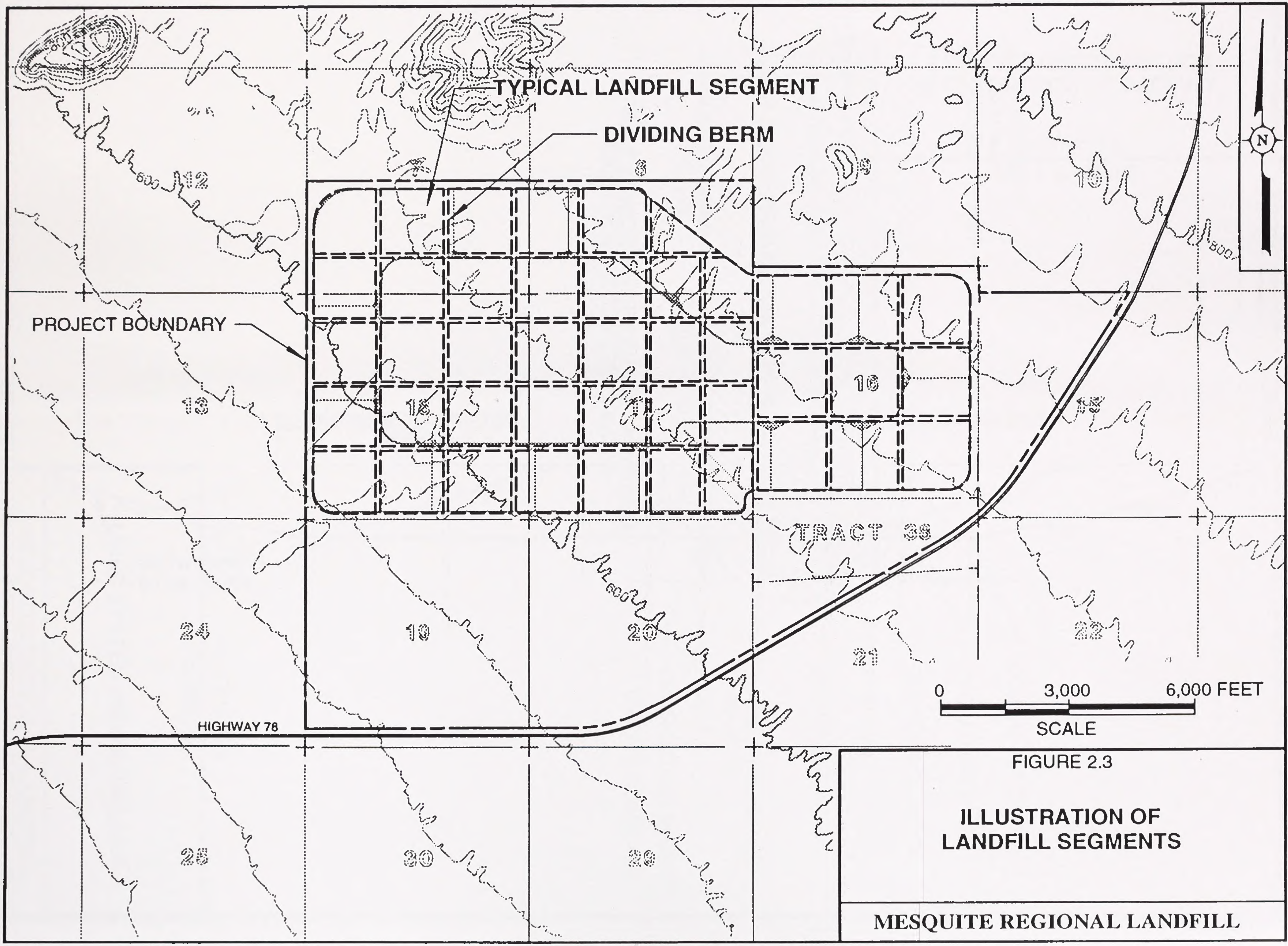
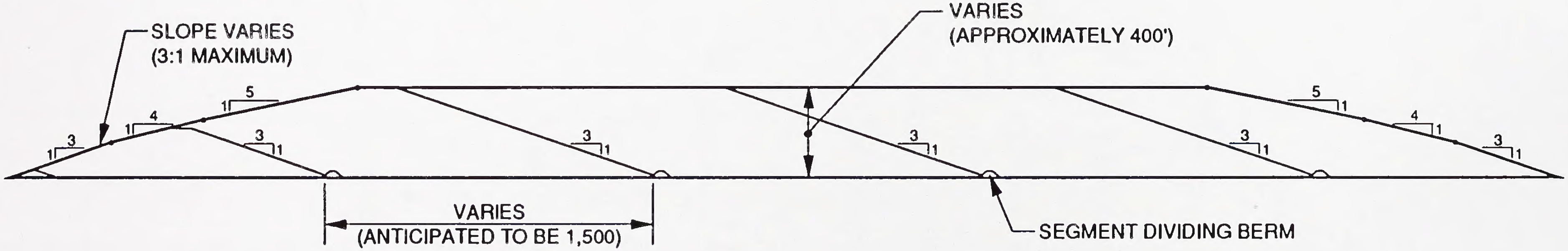


FIGURE 2.3

ILLUSTRATION OF LANDFILL SEGMENTS

MESQUITE REGIONAL LANDFILL

91-296HAR-13 REV.11/16/93



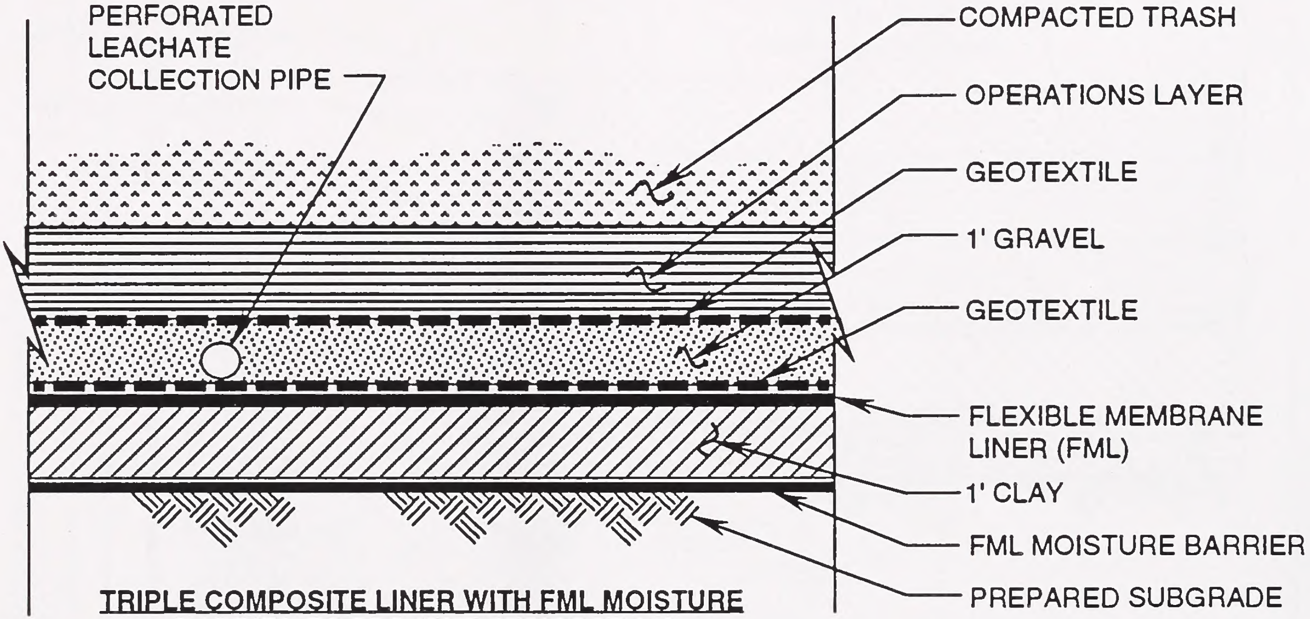
NOT TO SCALE

FIGURE 2.4

ILLUSTRATION OF OVERALL LANDFILL CROSS SECTION

MESQUITE REGIONAL LANDFILL

91-296 HAR-1001 REV. 8/30/93



TRIPLE COMPOSITE LINER WITH FML MOISTURE BARRIER TO PREVENT DESICCATION FOR MAIN CELL AREAS

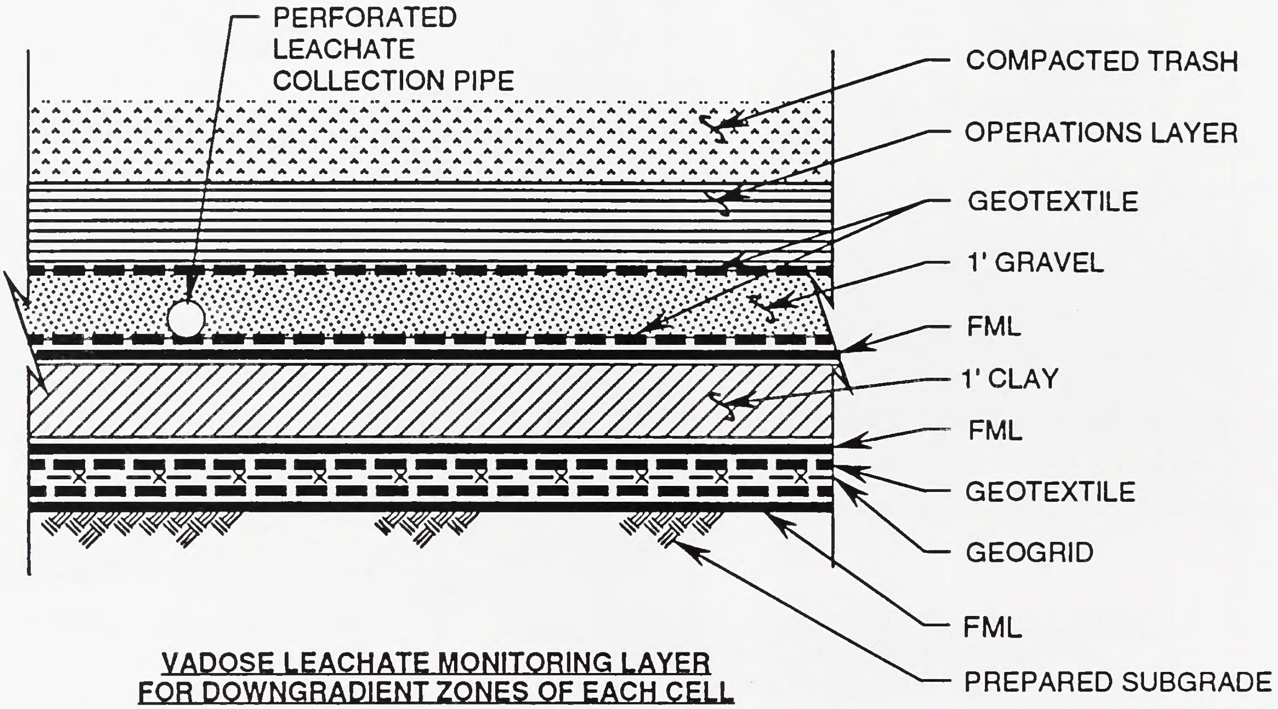
NOT TO SCALE

FIGURE 2.5

LINER SYSTEM DESIGN DETAILS

MESQUITE REGIONAL LANDFILL

91-296 HAR-1002 REV. 8/31/93



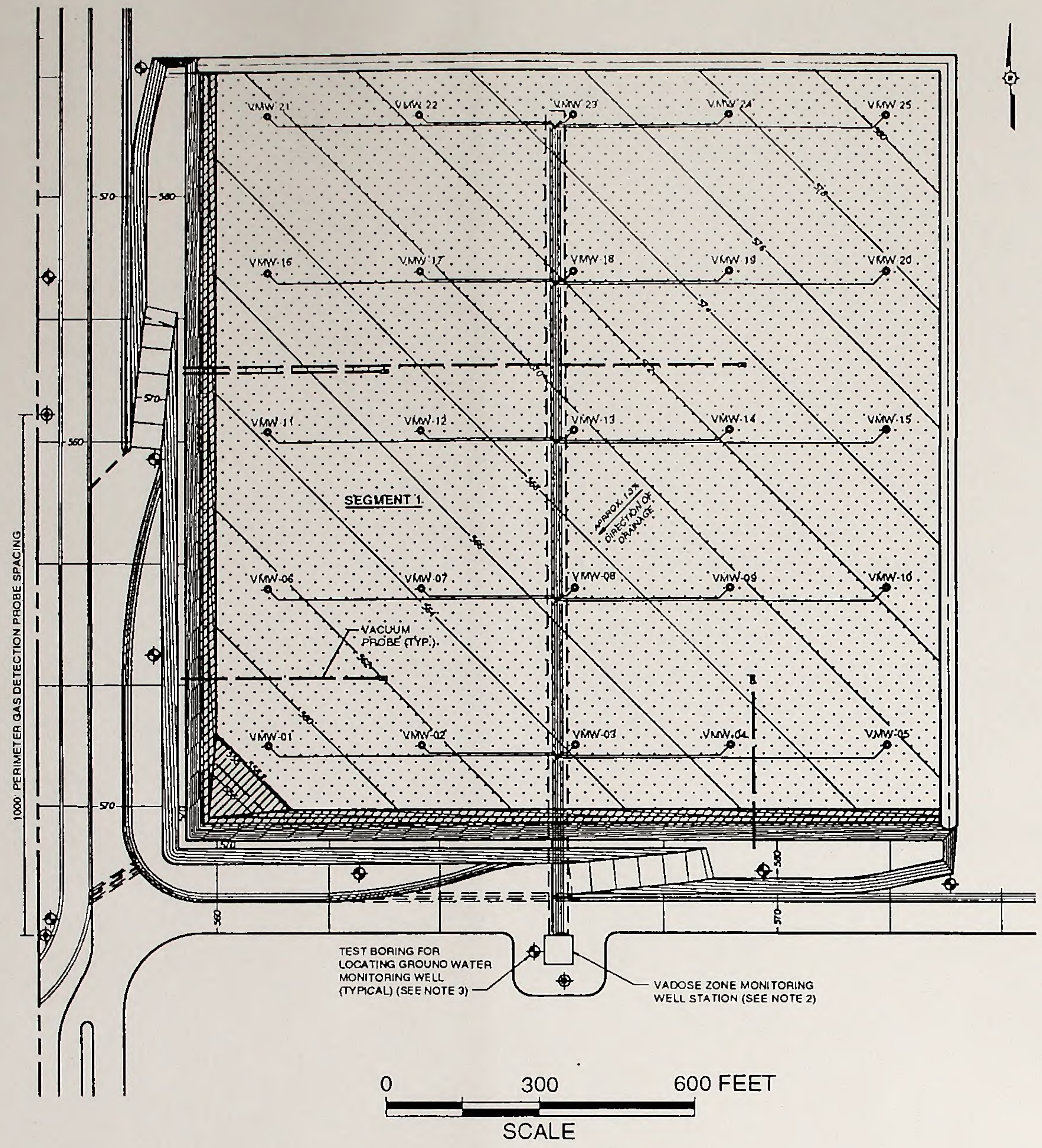
VADOSE LEACHATE MONITORING LAYER
FOR DOWNGRADIENT ZONES OF EACH CELL

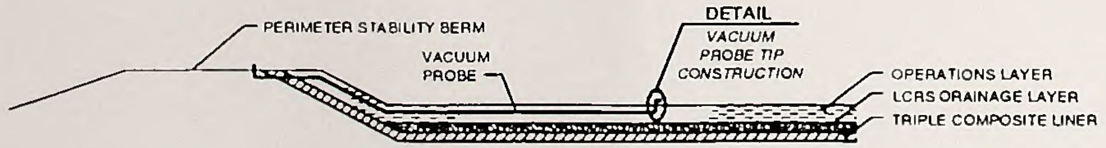
NOT TO SCALE

FIGURE 2.6

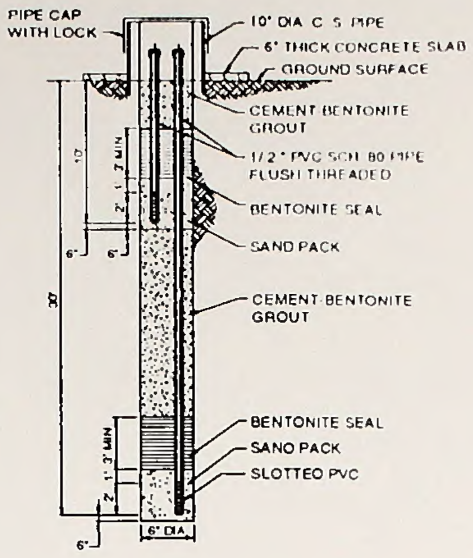
**VADOSE LEACHATE
MONITORING LAYER**

MESQUITE REGIONAL LANDFILL

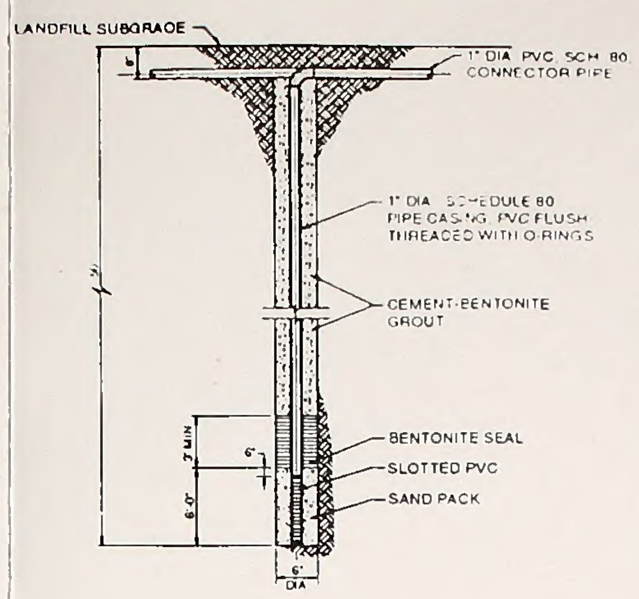




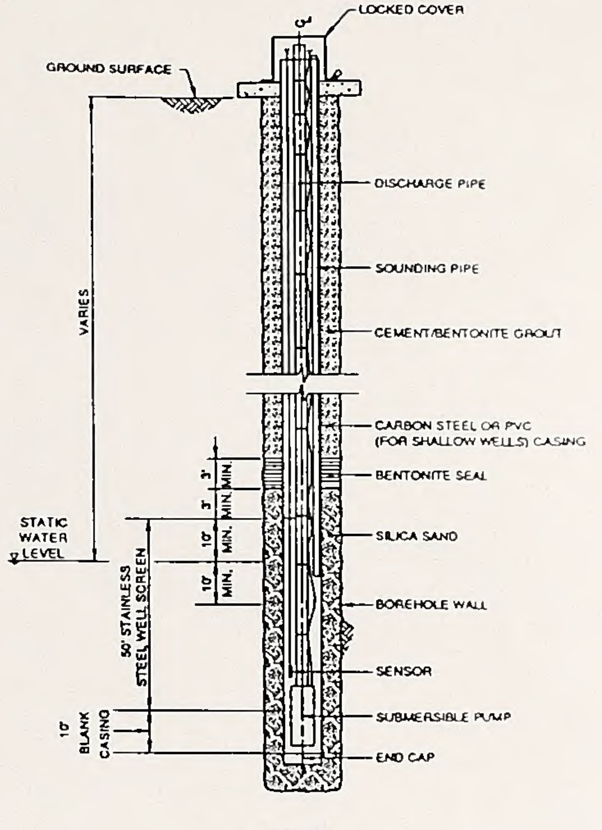
SECTION
AT TYPICAL VACUUM PROBE
NOT TO SCALE



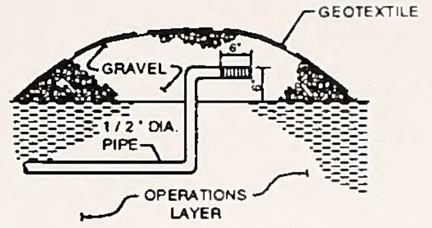
DETAIL
TYPICAL PERIMETER MONITORING PROBE
NOT TO SCALE


LANDFILL SUBGRADE
1" DIA. PVC SCH. 80 CONNECTOR PIPE
1" DIA. SCHEDULE 80 PIPE CASING PVC FLUSH THREADED WITH O-RINGS
CEMENT-BENTONITE GROUT
BENTONITE SEAL
SLOTTED PVC
SAND PACK
6"
6'-0"
2' MIN
6" DIA

DETAIL
TYPICAL VADOSE MONITORING WELL
NOT TO SCALE



DETAIL
TYPICAL GROUND WATER MONITORING WELL
NOT TO SCALE



DETAIL
VACUUM PROBE TIP CONSTRUCTION
NOT TO SCALE

LEGEND

⬚	TRIPLE COMPOSITE LINER AND LEACHATE CONTROL AND RECOVERY SYSTEM (LCRS)
▨	LOCATION OF VADOSE LEACHATE MONITORING LAYER (SEE NOTE 2)
•	VADOSE GAS MONITORING SYSTEM DETECTION WELL (SEE NOTE 2)
⊕	VADOSE ZONE GAS PERIMETER MONITORING PROBE
◈	TEST BORING FOR GROUND WATER MONITORING WELL PLACEMENT

NOTES

1. DIMENSIONS AND FACILITY ARRANGEMENTS ARE APPROXIMATE FOR ILLUSTRATION PURPOSES. DETAILS AND ULTIMATE CONFIGURATION WILL BE DETERMINED DURING FINAL DESIGN IN ACCORDANCE WITH RWQCB APPROVAL REQUIREMENTS.
2. THE VADOSE GAS MONITORING WELL AND VADOSE LEACHATE MONITORING LAYER SHOWN WILL BE INITIALLY PROVIDED AT SEGMENTS 1 AND 2. THE DECISION TO INCLUDE THESE MONITORING SYSTEMS AT FUTURE SEGMENTS WILL BE MADE AT THE INITIAL 5-YEAR RWQCB AND LEA REVIEWS.
3. EXPERIENCE HAS SHOWN THAT BOREHOLES DRILLED INTO BASEMENT ROCK ARE OFTEN DRY IF FRACTURES ARE NOT ENCOUNTERED. IF NECESSARY, MULTIPLE BORINGS WILL BE DRILLED UNTIL MEASURABLE GROUND WATER IS ENCOUNTERED. THE BORING WITH MEASUREABLE WATER WILL BE COMPLETED AS SHOWN. THE DRY BORINGS WILL BE SEALED WITH A CEMENT/BENTONITE GROUT.

FIGURE 2.7

MONITORING SYSTEM PLAN AND DETAILS

MESQUITE REGIONAL LANDFILL

91-296 HAR REV. 8/31/93

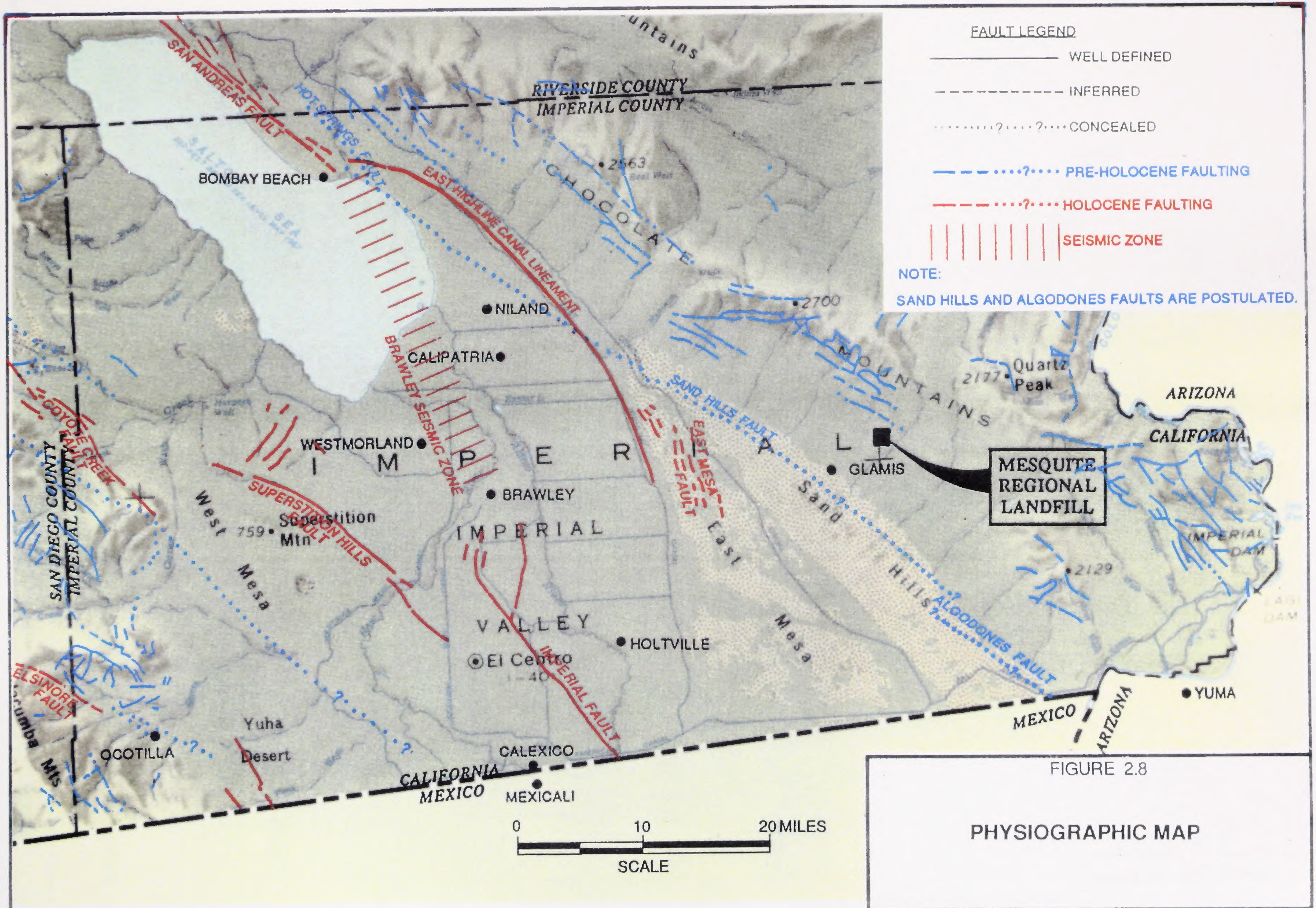
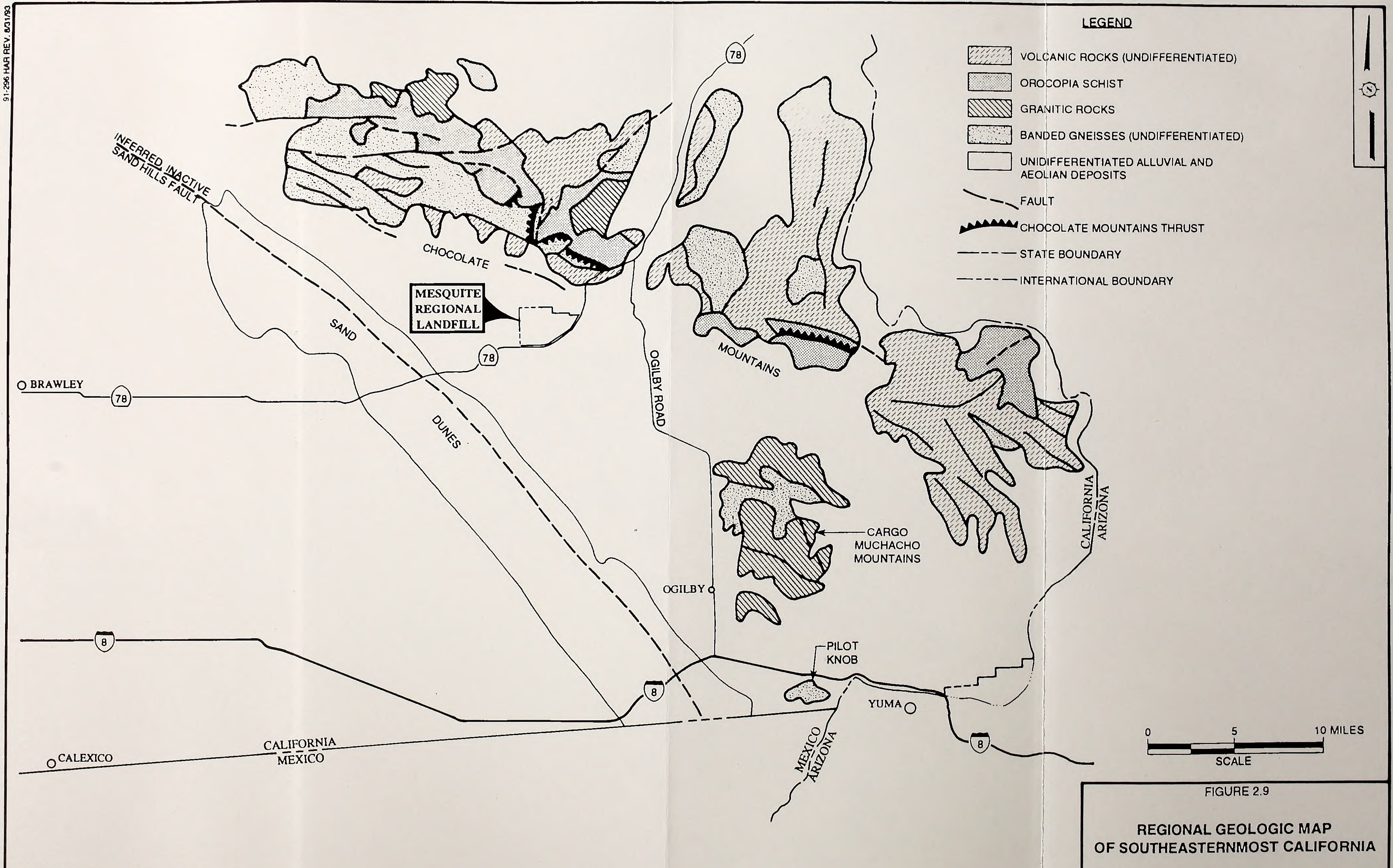


FIGURE 2.8

PHYSIOGRAPHIC MAP

MESQUITE REGIONAL LANDFILL

91-296 HAR REV. 8/31/93



REFERENCES: 1. ADAPTED FROM MORTON, 1977.

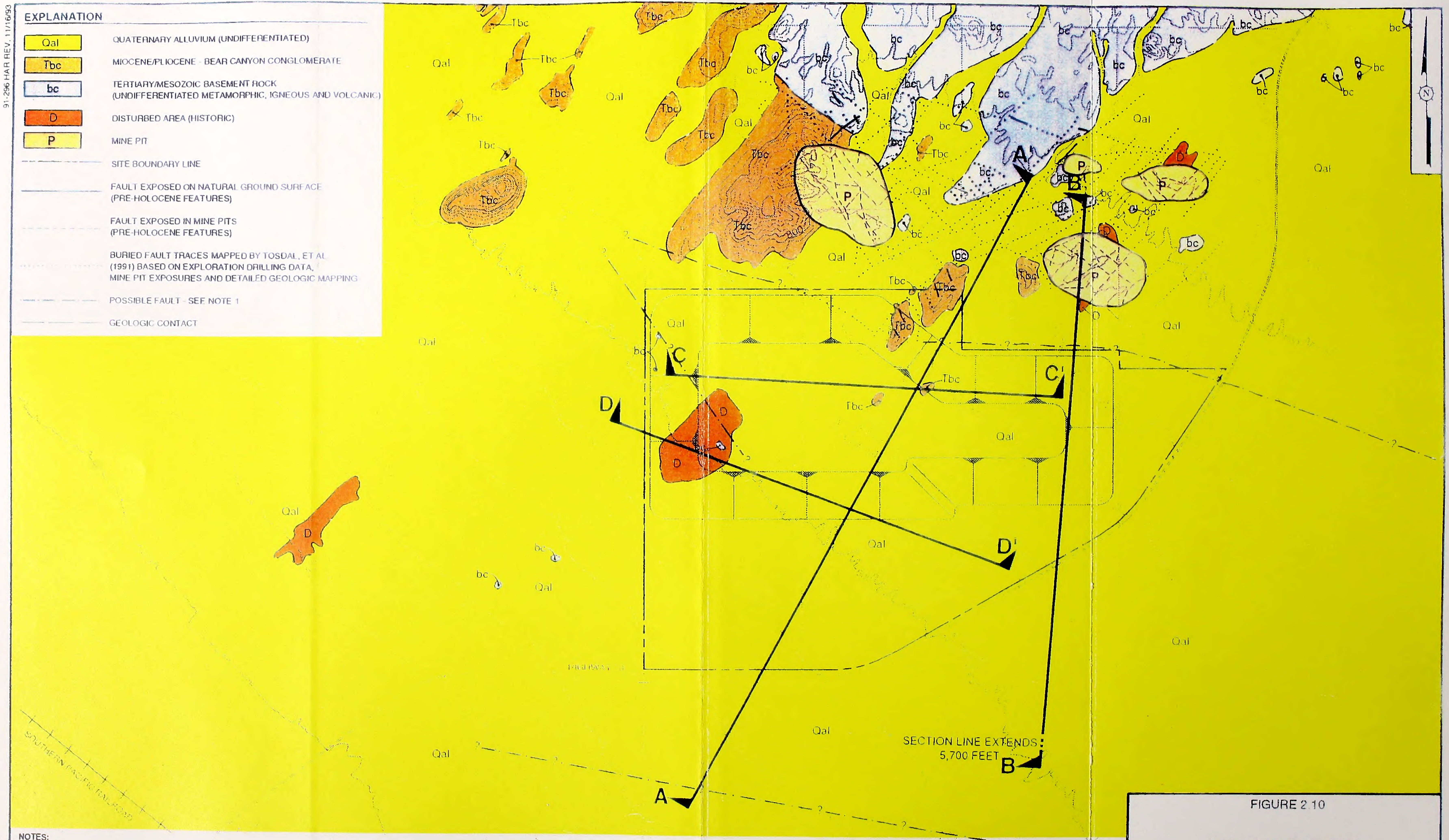
2. 1 X 2 DEGREE USGS TOPOGRAPHIC QUAD MAPS OF EL CENTRO AND SALTON SEA, CALIFORNIA.

FIGURE 2.9

REGIONAL GEOLOGIC MAP OF SOUTHEASTERNMOST CALIFORNIA

MESQUITE REGIONAL LANDFILL

91-296 HAR REV. 11/16/93



EXPLANATION

Qal	QUATERNARY ALLUVIUM (UNDIFFERENTIATED)
Tbc	MIOCENE/PLIOCENE - BEAR CANYON CONGLOMERATE
bc	TERTIARY/MESOZOIC BASEMENT ROCK (UNDIFFERENTIATED METAMORPHIC, IGNEOUS AND VOLCANIC)
D	DISTURBED AREA (HISTORIC)
P	MINE PIT
— - — - —	SITE BOUNDARY LINE
———	FAULT EXPOSED ON NATURAL GROUND SURFACE (PRE-HOLOCENE FEATURES)
- - - - -	FAULT EXPOSED IN MINE PITS (PRE-HOLOCENE FEATURES)
········	BURIED FAULT TRACES MAPPED BY TOSDAL, ET AL (1991) BASED ON EXPLORATION DRILLING DATA, MINE PIT EXPOSURES AND DETAILED GEOLOGIC MAPPING
— · — · —	POSSIBLE FAULT - SEE NOTE 1
— — —	GEOLOGIC CONTACT

NOTES:

1. THIS FEATURE IS A SURFACE PROJECTION OF A ZONE WHERE BURIED BASEMENT ROCK DEEPENS. THIS COULD BE THE RESULT OF PRE-HOLOCENE FAULTING, OR EROSION, OR BOTH.
2. EXCEPT FOR THE MINE PITS, GEOLOGY SHOWN IS PRE-MINE DEVELOPMENT.
3. SEE FIGURE 2.11 FOR CROSS SECTIONS.

0 3,000 6,000 FEET

SCALE

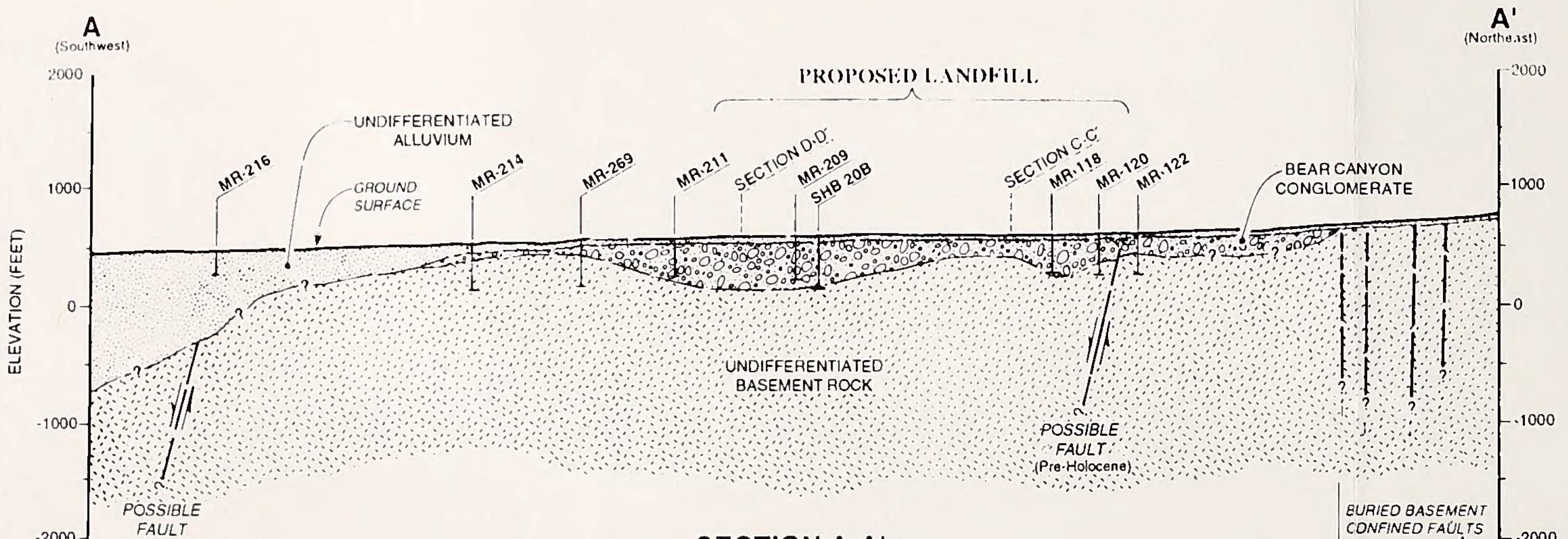
CONTOUR INTERVAL: 40 FEET

FIGURE 2.10

SITE GEOLOGIC MAP

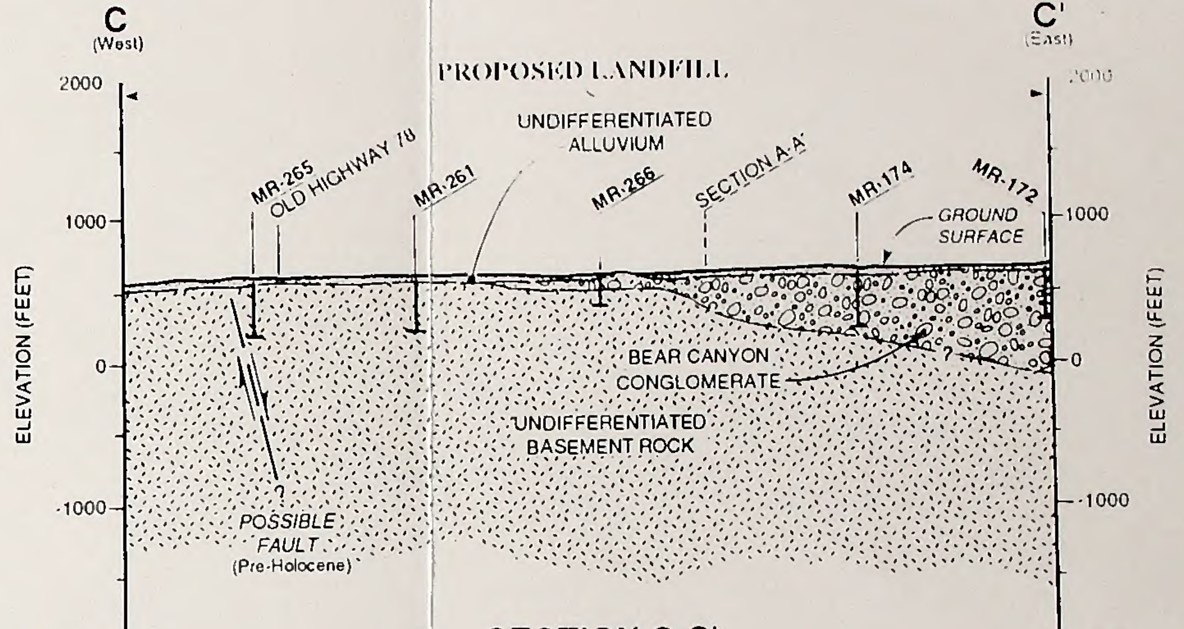
MESQUITE REGIONAL LANDFILL

91-296 HAR REV. 11/15/93



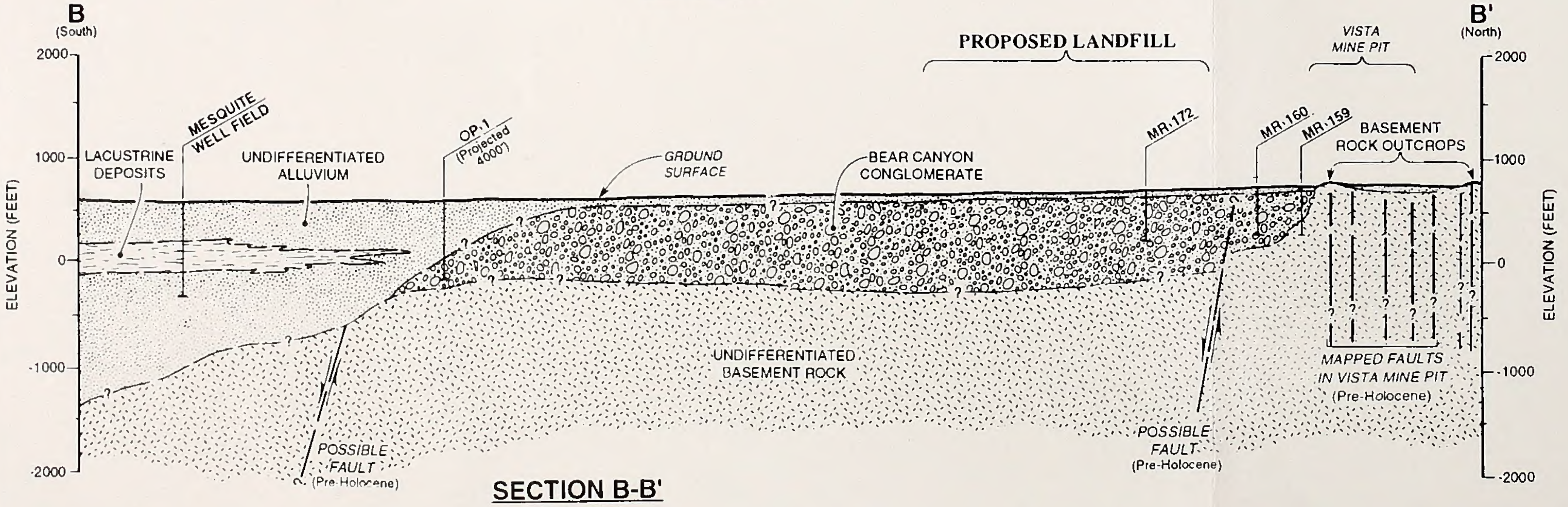
SECTION A-A'

(Looking Northwest)



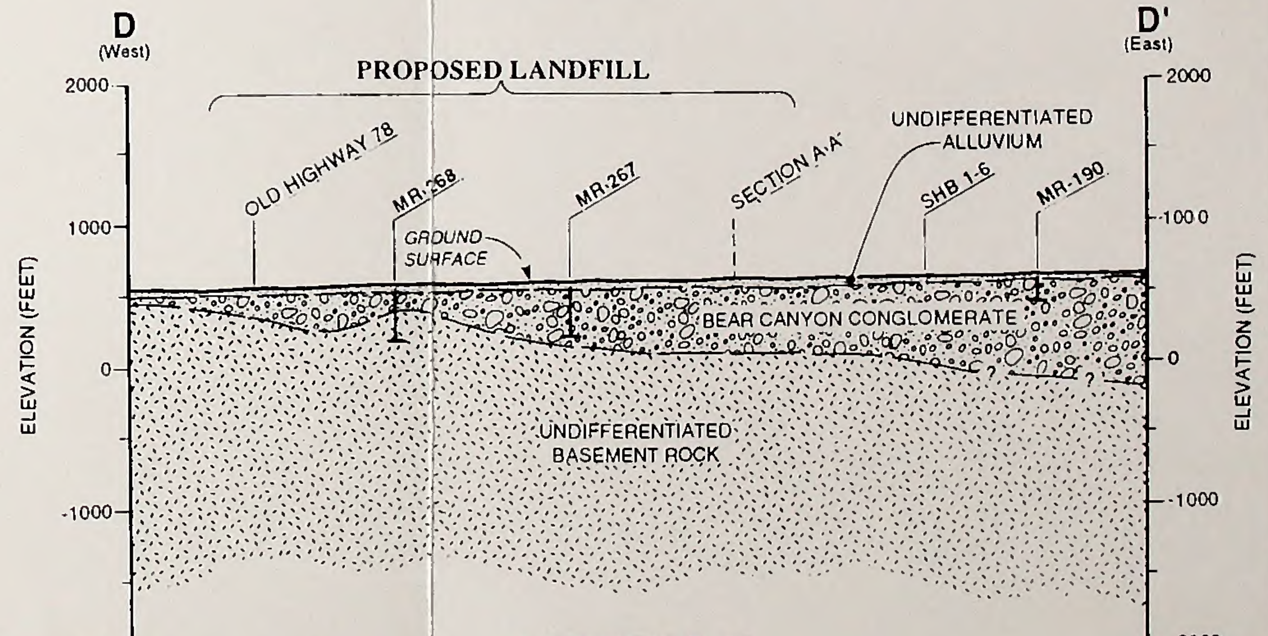
SECTION C-C'

(Looking North)



SECTION B-B'

(Looking West)



SECTION D-D'

(Looking North)

0 3,000 6,000 FEET

HORIZONTAL SCALE

0 1,500 3,000 FEET

VERTICAL SCALE

NOTES:

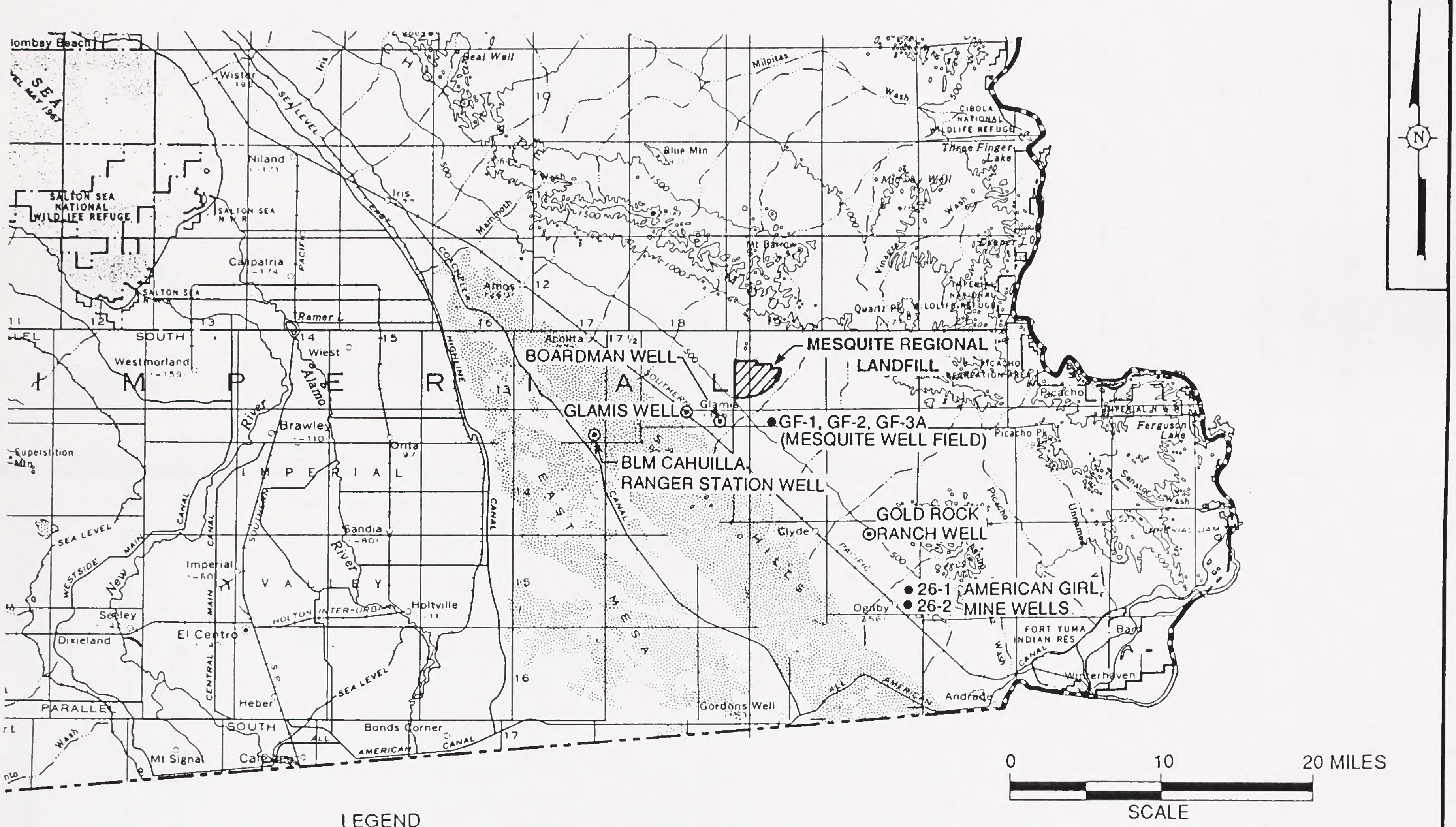
1. ALL SECTIONS DRAWN ON PRE-MINE DEVELOPMENT SURFACE.
2. SEE FIGURE 2.10 AND 3.6 FOR CROSS SECTION LOCATIONS.

FIGURE 2.11

GEOLOGIC CROSS SECTIONS

MESQUITE REGIONAL LANDFILL

91-296HAR REV. 3/25/93



LEGEND

- ⊙ LOW CAPACITY DOMESTIC WELLS
- ● HIGH CAPACITY INDUSTRIAL WELLS

FIGURE 3.1

SITE VICINITY PRODUCTION AND WATER WELLS

MESQUITE REGIONAL LANDFILL

91-296HAR-10 REV 11/16/93

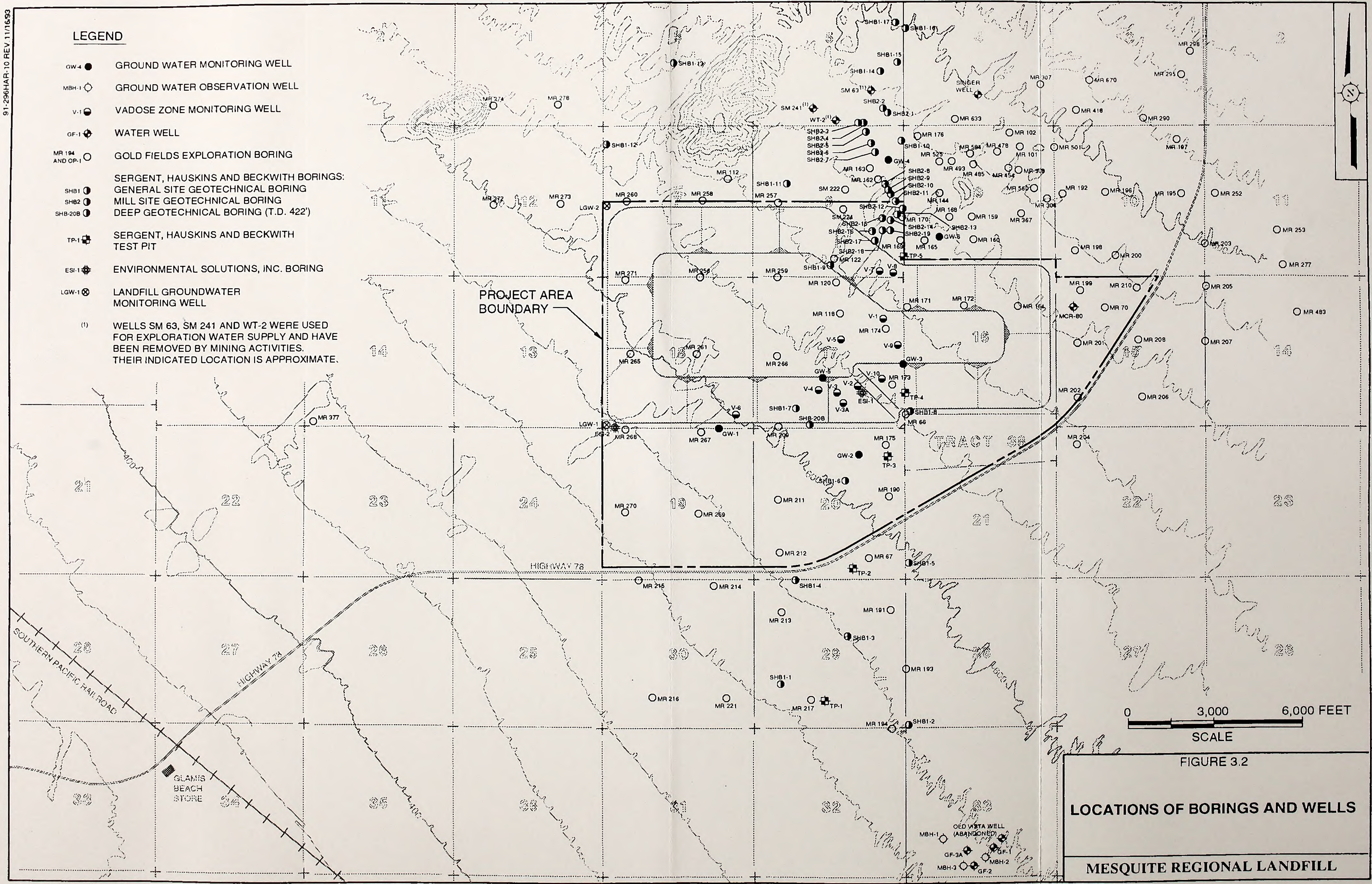
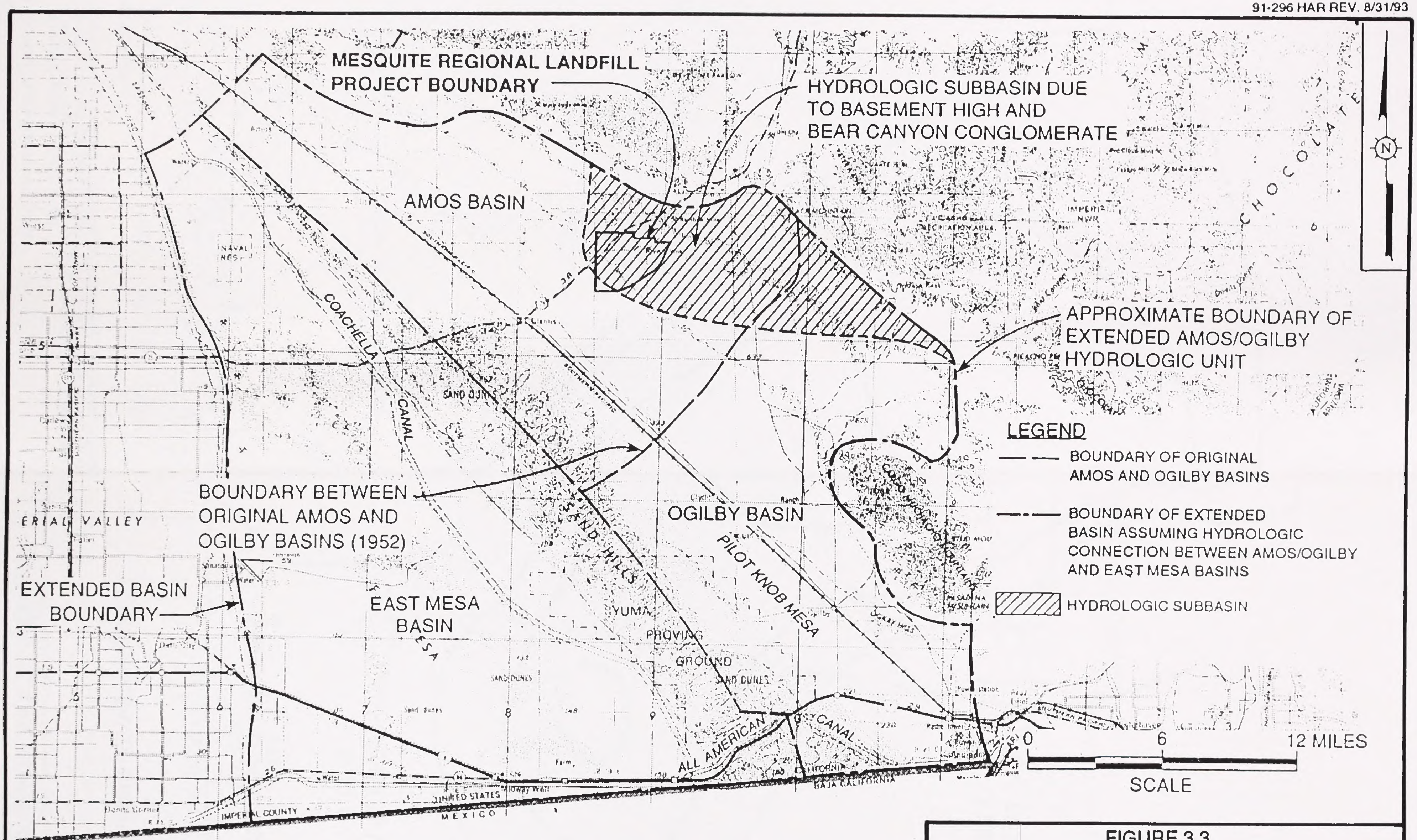

LEGEND
GW-4 ● GROUND WATER MONITORING WELL
MBH-1 GROUND WATER OBSERVATION WELL
V-1 VADOSE ZONE MONITORING WELL
GF-1 WATER WELL
MR 194 AND OP-1 ○ GOLD FIELDS EXPLORATION BORING
SERGENT, HAUSKINS AND BECKWITH BORINGS:
SHB1 GENERAL SITE GEOTECHNICAL BORING
SHB2 MILL SITE GEOTECHNICAL BORING
SHB-20B DEEP GEOTECHNICAL BORING (T.D. 422')
TP-1 SERGENT, HAUSKINS AND BECKWITH TEST PIT
ESI-1 ENVIRONMENTAL SOLUTIONS, INC. BORING
LGW-1 ⊗ LANDFILL GROUNDWATER MONITORING WELL
(1) WELLS SM 63, SM 241 AND WT-2 WERE USED FOR EXPLORATION WATER SUPPLY AND HAVE BEEN REMOVED BY MINING ACTIVITIES. THEIR INDICATED LOCATION IS APPROXIMATE.
PROJECT AREA BOUNDARY
HIGHWAY 78
SOUTHERN PACIFIC RAILROAD
GLAMIS BEACH STORE
TRACT 38
SINGER WELL
OLD VISTA WELL (ABANDONED)
0
3,000
6,000 FEET
SCALE

FIGURE 3.2

LOCATIONS OF BORINGS AND WELLS

MESQUITE REGIONAL LANDFILL

91-296 HAR REV. 8/31/93

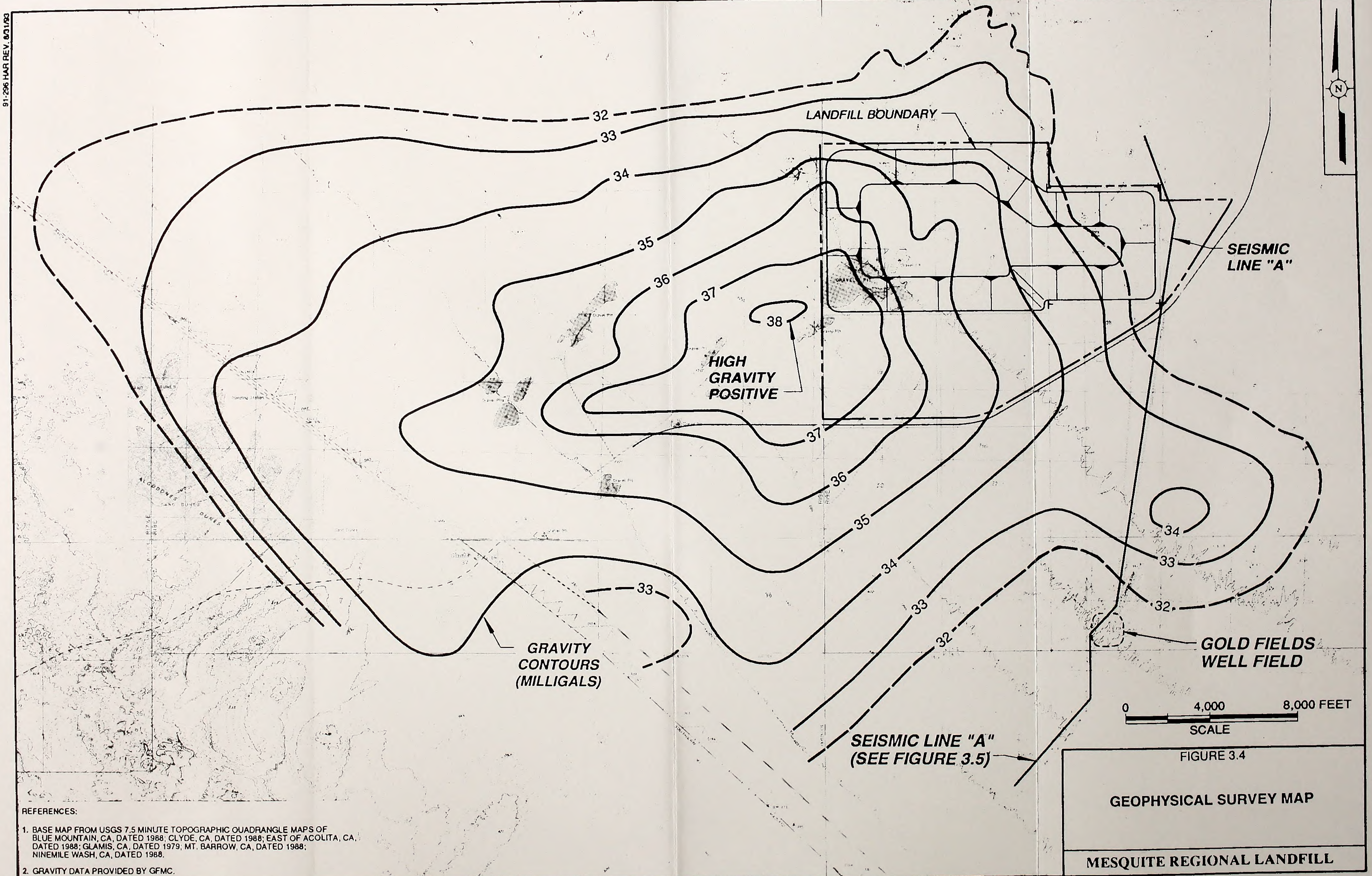

MESQUITE REGIONAL LANDFILL PROJECT BOUNDARY
HYDROLOGIC SUBBASIN DUE TO BASEMENT HIGH AND BEAR CANYON CONGLOMERATE
AMOS BASIN
APPROXIMATE BOUNDARY OF EXTENDED AMOS/OGILBY HYDROLOGIC UNIT
CHOCOLATE
N
LEGEND
BOUNDARY OF ORIGINAL AMOS AND OGILBY BASINS
BOUNDARY OF EXTENDED BASIN ASSUMING HYDROLOGIC CONNECTION BETWEEN AMOS/OGILBY AND EAST MESA BASINS
HYDROLOGIC SUBBASIN
BOUNDARY BETWEEN ORIGINAL AMOS AND OGILBY BASINS (1952)
OGILBY BASIN
PILOT KNOB MESA
SAND HILLS
COACHELLA CANAL
SAND DUNES
EXTENDED BASIN BOUNDARY
EAST MESA BASIN
MESA
YUMA PROVING GROUND
ALL AMERICAN CANAL
IMPERIAL VALLEY
NAVAL RES
UNITED STATES
MEXICO
IMPERIAL COUNTY
BAJA CALIFORNIA
0
6
12 MILES
SCALE

SOURCE: CALIFORNIA DEPARTMENT OF PUBLIC WORKS 1952 AND 1964; DUTCHER, 1972; AND LOELTZ, 1975.

FIGURE 3.3

GROUND WATER BASIN BOUNDARIES

MESQUITE REGIONAL LANDFILL



REFERENCES:

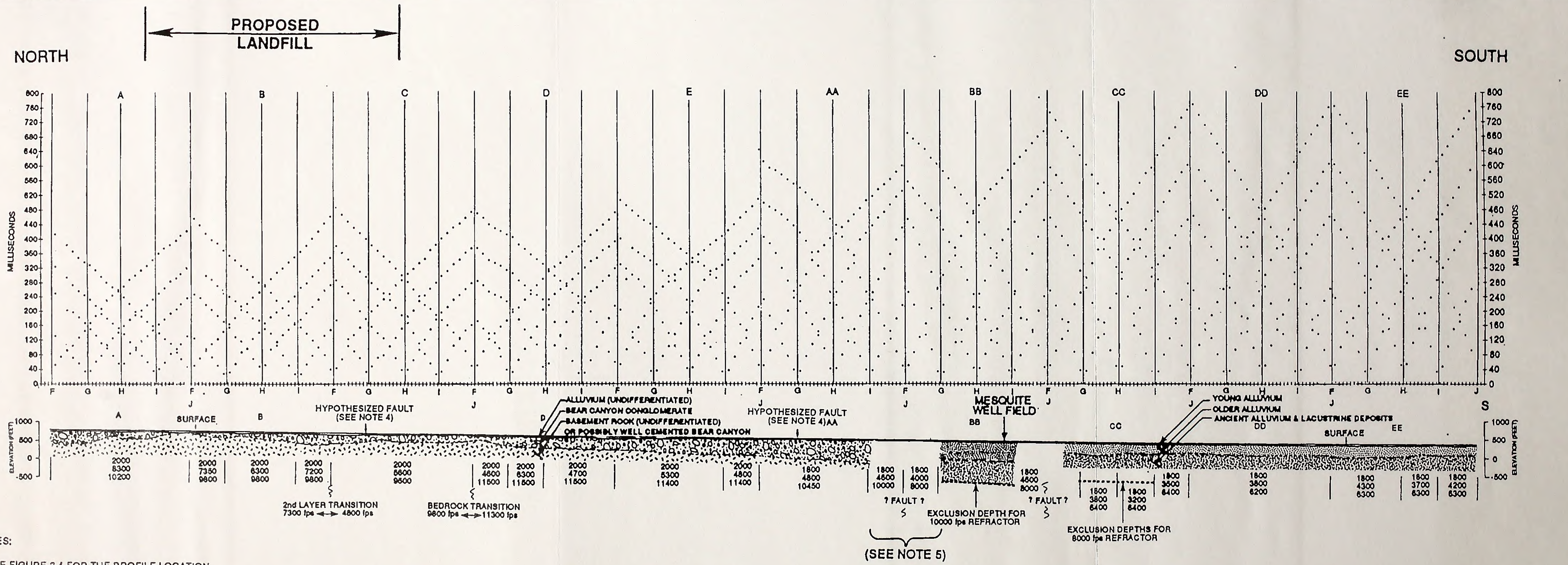
1. BASE MAP FROM USGS 7.5 MINUTE TOPOGRAPHIC QUADRANGLE MAPS OF BLUE MOUNTAIN, CA, DATED 1988; CLYDE, CA, DATED 1988; EAST OF ACOLITA, CA, DATED 1988; GLAMIS, CA, DATED 1979; MT. BARROW, CA, DATED 1988; NINEMILE WASH, CA, DATED 1988.
2. GRAVITY DATA PROVIDED BY GFMC.

FIGURE 3.4

GEOPHYSICAL SURVEY MAP

MESQUITE REGIONAL LANDFILL

91-298 HAR REV. 8/31/93



NOTES:

1. SEE FIGURE 3.4 FOR THE PROFILE LOCATION.

2. VELOCITIES SHOWN ARE IN FEET PER SECOND.

3. TOTAL LINE LENGTH 6.8 MILES, INCLUDING 10-3,600 FT. SPREADS WITH 150 FT. GEOPHONE SPACING AND 5-SHOT POINTS PER SPREAD. SLOPE INTERCEPT AND RECIPROCAL METHODS USED TO CALCULATE DEPTHS OF VELOCITY LAYERS.

4. THIS FAULT HYPOTHESIZED BY ALBERIO DOES NOT HAVE EXPRESSION IN OTHER EXISTING DATA.

5. THIS AREA REPRESENTS THE ZONE WHERE THE PEDIMENT ENDS AND THE ALLUVIUM THICKENS.

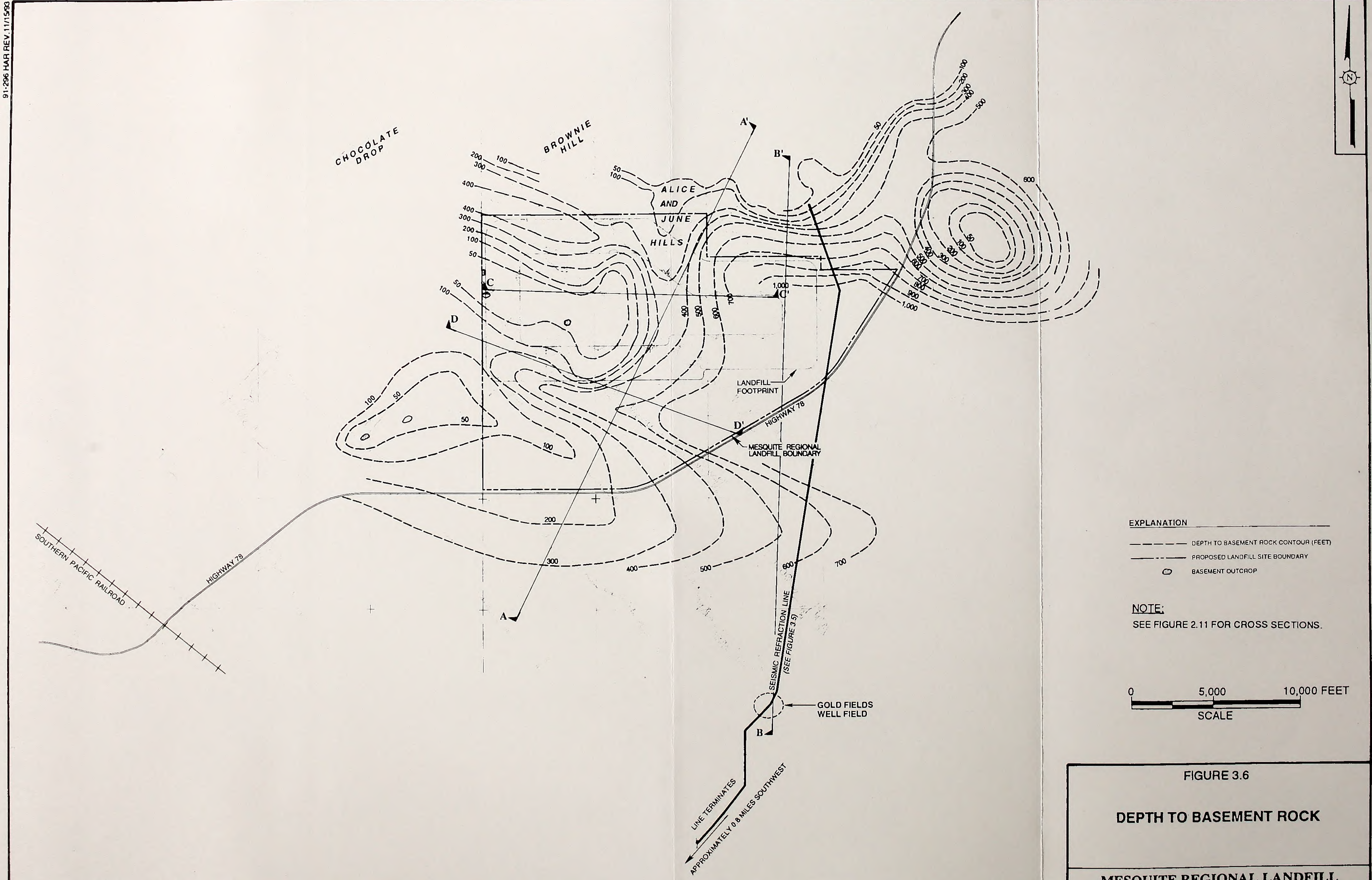
0 2,000 4,000 FEET
SCALE

FIGURE 3.5

SEISMIC REFRACTION
PROFILE LINE "A"

MESQUITE REGIONAL LANDFILL

91-296 HAR REV.11/15/93


CHOCOLATE DROP
BROWNIE HILL
ALICE AND JUNE HILLS
A'
B'
C
C'
D
D'
A
B
LANDFILL FOOTPRINT
HIGHWAY 78
MESQUITE REGIONAL LANDFILL BOUNDARY
SOUTHERN PACIFIC RAILROAD
HIGHWAY 78
SEISMIC REFRACTION LINE (SEE FIGURE 3.5)
GOLD FIELDS WELL FIELD
LINE TERMINATES APPROXIMATELY 0.8 MILES SOUTHWEST
50
100
200
300
400
500
600
700
800
900
1,000
N
EXPLANATION
DEPTH TO BASEMENT ROCK CONTOUR (FEET)
PROPOSED LANDFILL SITE BOUNDARY
BASEMENT OUTCROP
0
5,000
10,000 FEET
SCALE

NOTE:
SEE FIGURE 2.11 FOR CROSS SECTIONS.

FIGURE 3.6

DEPTH TO BASEMENT ROCK

MESQUITE REGIONAL LANDFILL

91-296HAR-07 REV 08/30/93

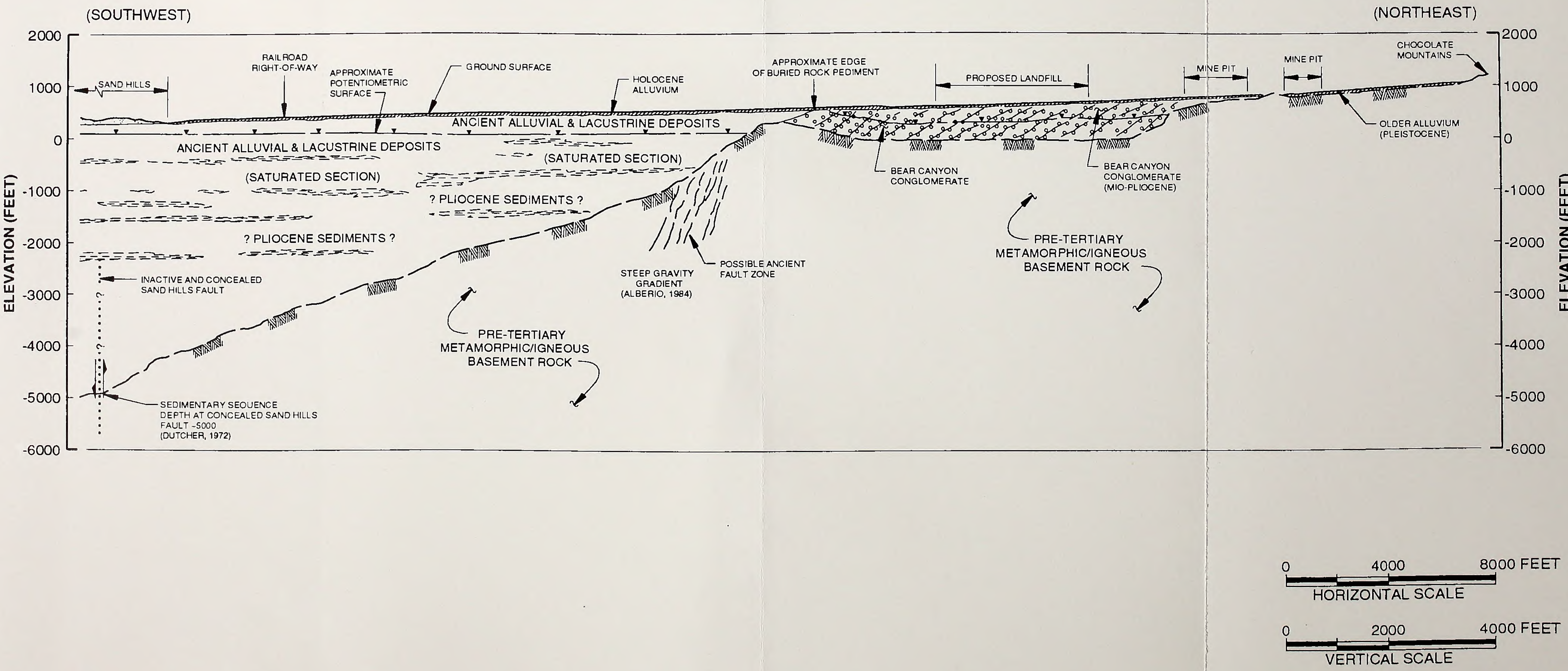
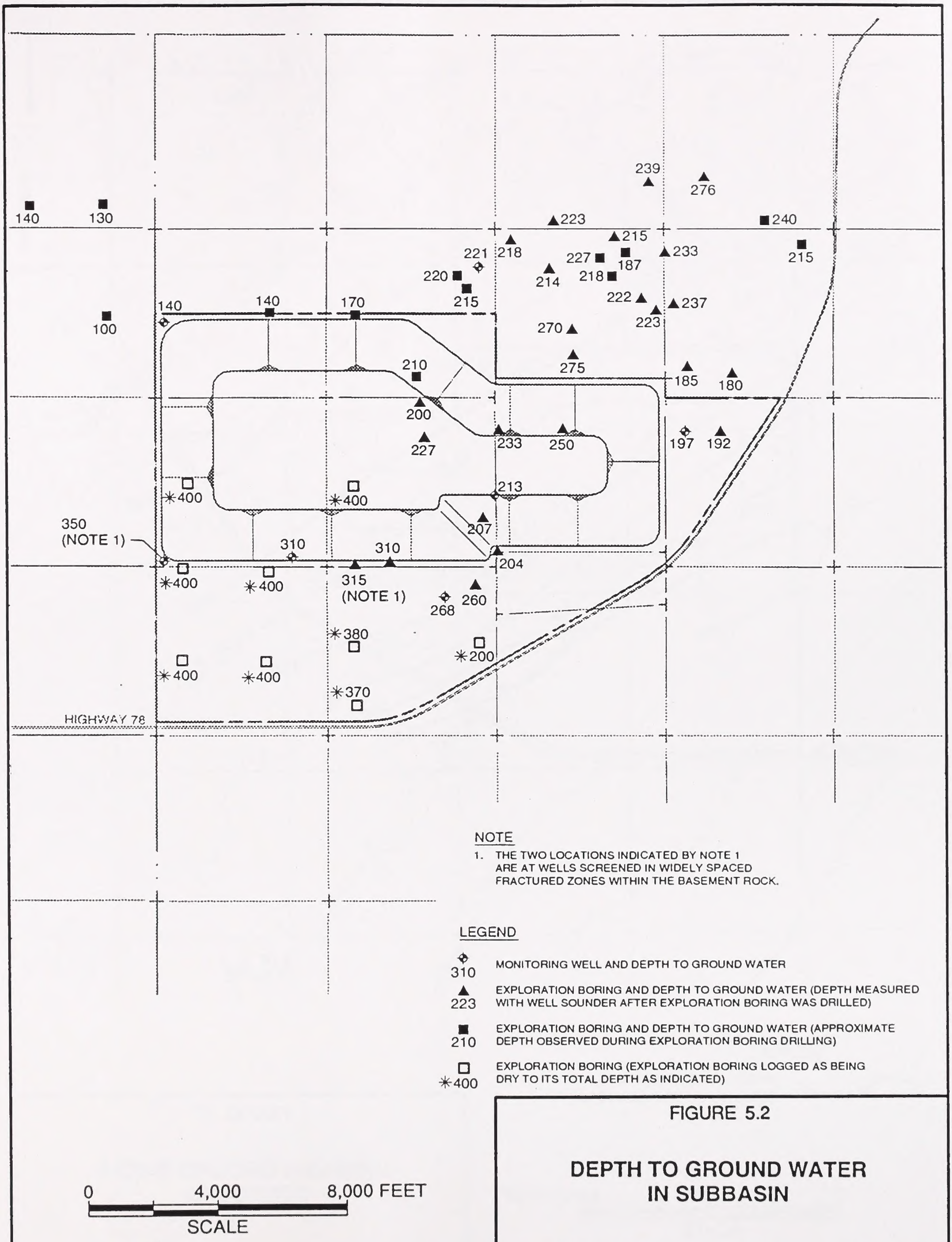

(SOUTHWEST)
(NORTHEAST)
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
ELEVATION (FEET)
SAND HILLS
RAILROAD RIGHT-OF-WAY
APPROXIMATE POTENTIOMETRIC SURFACE
GROUND SURFACE
HOLOCENE ALLUVIUM
APPROXIMATE EDGE OF BURIED ROCK PEDIMENT
PROPOSED LANDFILL
MINE PIT
MINE PIT
CHOCOLATE MOUNTAINS
ANCIENT ALLUVIAL & LACUSTRINE DEPOSITS
ANCIENT ALLUVIAL & LACUSTRINE DEPOSITS
(SATURATED SECTION)
(SATURATED SECTION)
? PLIOCENE SEDIMENTS ?
? PLIOCENE SEDIMENTS ?
OLDER ALLUVIUM (PLEISTOCENE)
BEAR CANYON CONGLOMERATE
BEAR CANYON CONGLOMERATE (MIO-PLIOCENE)
PRE-TERTIARY METAMORPHIC/IGNEOUS BASEMENT ROCK
PRE-TERTIARY METAMORPHIC/IGNEOUS BASEMENT ROCK
INACTIVE AND CONCEALED SAND HILLS FAULT
?
?
STEEP GRAVITY GRADIENT (ALBERIO, 1984)
POSSIBLE ANCIENT FAULT ZONE
SEDIMENTARY SEQUENCE DEPTH AT CONCEALED SAND HILLS FAULT ~5000 (DUTCHER, 1972)
0
4000
8000 FEET
HORIZONTAL SCALE
0
2000
4000 FEET
VERTICAL SCALE

FIGURE 5.1

SUBBASIN AND ALLUVIAL BASIN CROSS SECTION

MESQUITE REGIONAL LANDFILL

91-296 HAR-09 REV. 10/6/92



NOTE

1. THE TWO LOCATIONS INDICATED BY NOTE 1 ARE AT WELLS SCREENED IN WIDELY SPACED FRACTURED ZONES WITHIN THE BASEMENT ROCK.

LEGEND

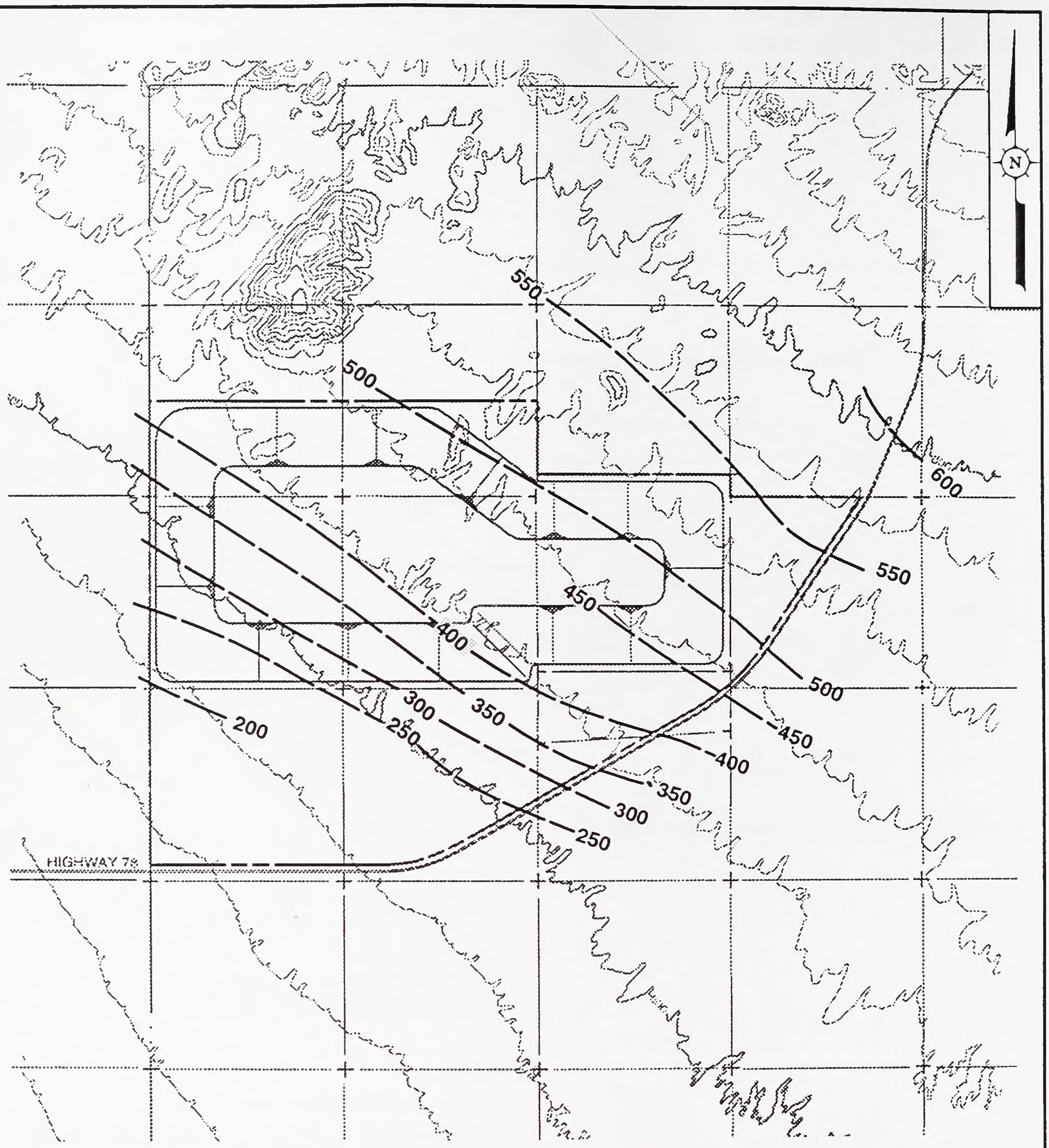
⊕ 310	MONITORING WELL AND DEPTH TO GROUND WATER
▲ 223	EXPLORATION BORING AND DEPTH TO GROUND WATER (DEPTH MEASURED WITH WELL SOUNDER AFTER EXPLORATION BORING WAS DRILLED)
■ 210	EXPLORATION BORING AND DEPTH TO GROUND WATER (APPROXIMATE DEPTH OBSERVED DURING EXPLORATION BORING DRILLING)
☐ ✳400	EXPLORATION BORING (EXPLORATION BORING LOGGED AS BEING DRY TO ITS TOTAL DEPTH AS INDICATED)

FIGURE 5.2

DEPTH TO GROUND WATER IN SUBBASIN

MESQUITE REGIONAL LANDFILL

91-296HAR-09 REV. 09/10/92



LEGEND

350 INTERPRETED DEPTH TO GROUND WATER CONTOUR

0 4,000 8,000 FEET
SCALE

FIGURE 5.3

SUBBASIN GROUND WATER CONTOURS

MESQUITE REGIONAL LANDFILL

APPENDIX A

MESQUITE MINE WDO NO. 89-034

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
COLORADO RIVER BASIN REGION

ORDER NO. 89-034

WASTE DISCHARGE REQUIREMENTS
FOR
GOLD FIELDS OPERATING CO. - MESQUITE
Northeast of Glamis - Imperial County

The California Regional Water Quality Control Board, Colorado River Basin Region, finds that:

1. Gold Fields Operating Co. - Mesquite (hereinafter also referred to as the discharger), HCR 76 Glamis 100, Brawley, California, 92227, submitted an updated Report of Waste Discharge, dated January 21, 1989, to modify an existing operation. The modification is an increase in the rate of gold ore processing, and modifications to the existing process configuration to account for operational improvements determined since the facility started up in February 1985.

2. The discharger proposes to provide flexibility for the rate of gold production on its approximately 1,200-acre heap leaching/carbon adsorption processing facility. The nominal processing rate is expected to be between about five and eight million tons per year. Larger production rates may be permitted provided the applicant demonstrates to the Executive Officer that the production rate increase will not cause noncompliance with storm run-off and solution volume containment requirements of this Order.

3. The main processing facilities are located in Sections 8, 9, 16, 17, 19 and 20, T13S, R19E, SBB&M, about 6 miles northeast of Glamis near Highway 78. Ore processed in this area would be mined in Sections 3, 4, 5, 6, 7, 8, 9, 10 and 15, T13S, R19E, SBB&M. Additional satellite processing facilities, if approved in writing by the Executive Officer, may be located in the areas indicated on the attached figure entitled "Approximate Areas That Could Include Future Satellite Pads".

4. The estimated life of the processing area is 20 years. The process will continue to use a solution of sodium cyanide, (or an equivalent cyanide compound) applied onto piles (heaps) of ore, to dissolve gold and transport it in lined ditches or pipes to solution containment basins or tanks. The pregnant solution is piped through carbon column units where gold is removed. Sodium cyanide (or an equivalent cyanide compound) is added to reconstitute the resulting barren solution which is recirculated to the process.

5. Ore piles to be leached will be underlain by a continuous synthetic (or equivalent natural) liner designed to be effective throughout the

processing life of each pile or segment. The liner design would be based on but not necessarily limited to the following factors:

a. The size of the ore particles in the initial lift, against the liner,

b. Maximum pile height,

c. Ore placement methods,

d. Subgrade preparation and/or overliner procedures, and

e. Provisions for controlling the hydraulic head of the solution on the liner.

6. Upon completion of the ore-leaching process, each pile or segment would be flushed with fresh water or otherwise rinse-treated after completion of leaching operations to reduce cyanide concentration to an acceptable level which would result in a mining waste classification of Group C, under Article 7, Subchapter 15, Chapter 3 of Title 23 of the California Code of Regulations. The pile would then be either abandoned in place or removed elsewhere.

7. Normal annual precipitation in this area is 3.5 inches, and normal annual surface evaporation is 9 feet; so that precipitation upon a surface is not capable of carrying dissolved material into the ground water.

8. The Water Quality Control Plan for the Colorado River Basin Region of California was adopted by the Regional Board on November 14, 1984. The beneficial use of the ground waters in Amos-Ogilby Hydrologic Unit, as set forth in the above Plan, is municipal supply.

9. The processing facilities are located in an area underlain by bedrock with low potential for water supply. The depth to this limited ground water is approximately 200 feet. The industrial water supply for this project is derived from three deep wells drilled into alluvium, approximately two miles southeast of the processing facilities. The beginning of the alluvium basin, known as the Amos-Ogilby Hydrologic Unit, is estimated to be about one mile from the maximum limits of the processing facilities. Potable water at the mine is obtained by treating the local ground water with a reverse osmosis method to reduce naturally high constituents to acceptable drinking water standards. Ground water quality in the project area is sodium chloride in character with a total dissolved solids concentration of approximately 1700 mg/l. This 1700 mg/l is the average TDS value for samples taken from four ground water monitoring wells at the processing site prior to commencement of heap leach operations.

10. Overburden soil and rock, and waste rock from the mining operations would be deposited in piles surrounding the mining pits. These materials have the classification of Group C per Article 7 of said

Subchapter 15, based on laboratory tests on crushed rock which show that the material is not acid generating or hazardous, and would not cause discharge having a significant affect on water quality.

11. The Regional Board has notified the discharger and interested agencies and persons of its intent to revise waste discharge requirements for this facility.

12. The Regional Board, in a public meeting, heard and considered all comments pertaining to the proposed discharge.

13. The Imperial County Planning Commission adopted on December 12, 1984, Environmental Impact Report - SCH #84040408 which contains mitigation measures for the Mesquite Gold Mine and Processing Facilities on Sections 4, 5, 6, 7, 8, 9, 17, 18, 19 and 20, T13S, R19E, SBB&M. The Imperial County Planning Commission adopted on October 28, 1987, Environmental Impact Report SCH #87052709, which contains mitigation measures for expanded mining areas encompassed by Sections 3, 4, 9, 10 and 15, T13S, R19E, SBB&M. In March 1989, the Imperial County Planning Commission adopted a Negative Declaration finding no significant impact for the modifications currently proposed by the discharger. These EIR's and the Negative Declaration indicate that this project would not have a significant affect on water quality.

IT IS HEREBY ORDERED, the discharger shall comply with the following:

A. Discharge Specifications

1. Neither the mining process nor the discharge of wastewater or other wastes shall create pollution or nuisance as defined in Division 7 of the California Water Code.

2. The cyanide solutions shall be contained only in the processing system or in other leak-proof containers.

3. There shall be no wind transport of cyanide solution or ore containing cyanide away from the leaching area.

4. The heap leach ore piles shall be underlain by a synthetic liner which has a maximum permeability of 1×10^{-18} cm/sec and a minimum thickness of 40 mils. An equivalent liner may be approved by the Regional Board's Executive Officer if the discharger demonstrates that the equivalent liner will function equal to or better than the above-specified minimum system. Any pad designed and constructed prior to the effective date of this Order may utilize 36 mil reinforced liners at the edges of the pads.

5. The pregnant and intermediate solution ditches (which are not trunk ditches) and adjacent solution collection and freeboard areas shall be lined with a reinforced weather-resistant synthetic liner which has a minimum thickness of 36 mils and a permeability which does not exceed

1×10^{-10} cm/sec, or an equivalent liner approved by the Executive Officer.

6. Each cyanide solution containment basin, each cyanide-bearing sludge containment basin, and each trunk cyanide solution transport ditch, shall be underlain by a double liner with a leachate collection and removal system installed between the two synthetic liners, or an equivalent double containment system approved by the Executive Officer prior to construction. Each synthetic liner shall have a permeability which does not exceed 1×10^{-10} cm/sec. The bottom liner shall have a minimum thickness of 40 mils. The upper liner shall be equivalent to a reinforced weather-resistant synthetic material with a minimum thickness of 36 mils. Each basin shall contain a double-lined leak detection and withdrawal sump. Each double-lined trunk transport ditch shall contain leak detection and withdrawal sumps at approximately 1,000-foot intervals. The double liners with leachate collection and removal system shall extend up the sidewalls to at least the following heights (vertical) above the maximum working depth of the cyanide solution and/or sludge contained therein:

   a. 2.0 feet as regards basins

   b. 1.3 feet as regards trunk transport ditches (except as required in Specification No. 10, below).

   The remaining sidewalls of both basins and transport ditches shall have a single 36 mils reinforced weather-resistant synthetic liner, or an equivalent liner approved by the Regional Board's Executive Officer. Other design details for protection of the quality of the State waters shall also be approved by the Executive Officer. If tanks are used for containment of processing solutions, such tanks shall be situated within a lined and diked area designed to contain potential spillage or leakage of the entire tank volume and either: (1) be located entirely above ground, or (2) provided with a double liner and leak detection and recovery sump if located partially underground. Tank designs shall also comply with other applicable laws and regulations. Lined, diked areas for the sole purpose of temporary storage (less than 60 days) of tank leakage and/or infrequent storm run-off from the processing area shall have a single 36 mil reinforced weather-resistant synthetic liner, or an equivalent liner approved by the Executive Officer.

7. The liner system shall be documented by the discharger and approved by the Executive Officer to be able to withstand the static and dynamic loads that will be applied to the liner system.

8. All drainage and collection facilities used to contain or transport leaching solutions shall be effectively sealed to prevent leakage of these liquids.

9. The processing area shall be protected from any run-on, washout, or erosion which could occur as a result of a storm having a predicted

frequency of once in 100 years, and based on time of concentration at the processing area, as set forth in Department of Water Resources Bulletin No. 195 for El Centro, Blythe, and Hayfield, California and Yuma, Arizona. The average value shall be taken from these four reporting stations.

10. The heap leach processing area shall be diked, and containment basins (or an equivalent storage facility) shall be provided to contain all storm water drainage from the piles and from the cyanide solution collection and transport facilities during a maximum probable one-hour storm, as set forth in Department of Water Resources Bulletin No. 195 for El Centro, Blythe, and Hayfield, California and Yuma, Arizona. The average value (3.0 inches) taken from these four reporting stations is to be used. In addition, containment capacity shall be provided for 24 hours of cyanide solution draindown from the piles. Also, standby emergency facilities shall be available to assure continual circulation of the leaching solution if, at any time, it is determined that a planned processing configuration or rate could in an emergency result in a flow in excess of existing basin storage capacity. The additional storm storage capacity shall be provided before the new processing configuration is started.

11. The impoundment area dikes and containment basins shall provide at least two feet of freeboard above the storage volumes required in Discharge Specification No. 10 above. Transport ditches at the downgradient perimeter of the process area shall include at least two feet of freeboard for flows during a 100-year storm frequency and the ditch capacity with freeboard shall have an area capable of transporting runoff from the maximum probable one-hour storm.

12. There shall be no discharge of process wastewater at any location without prior approval from the Regional Board.

13. Adequate measures shall be taken to insure that liners will not be punctured for the duration of the leaching activity.

14. Leached ore residual shall not be placed in perennial, intermittent, or ephemeral stream channels unless provisions are made to divert runoff around the waste in a non-erosive manner. Waste shall not be placed where it can be eroded by stream flows or cause accelerated streambank erosion.

15. Prior to removal of leach ore residue from an impervious pad, for disposal, the cyanide contained therein shall be neutralized as described in Discharge Specification No. 19, below.

16. Ore residue may be abandoned on a pad, provided the cyanide in the ore is neutralized as described in Discharge Specification No. 19, below.

17. All industrial waste materials not covered by said Article 7, Subchapter 15 shall be discharged at a Regional Board-approved waste

management unit. Any hazardous waste containers shall be rendered unusable prior to final disposal.

18. Adequate measures shall be taken to assure that unauthorized persons are effectively excluded from the processing area.

19. When abandoning leached ore residue, the procedure for determination of whether free cyanide (CN-) in the ore residue has been neutralized to a satisfactory level shall be as follows:

    a. A sampling grid of the ore pile or segment on the leach pad shall be submitted that is acceptable to the Executive Officer. The sampling grid shall contain a total of at least ten sampling locations on the ore pile or segment being abandoned.

    b. The sample to be analyzed from each sampling location shall contain 100 grams as an aliquot of samples taken as set forth below, except that no sample shall be taken within three feet above the plastic liner unless special provisions are made to avoid penetrating the liner or for sealing said penetrations:

        1. An ore pile thirty feet or less in depth shall have samples taken at 25, 50 and 75 percent of the depth.

        2. An ore pile greater than thirty feet in depth shall have samples taken every ten feet of depth.

    c. The sample analysis procedure shall be set forth in Attachment A.

    d. The maximum allowable free cyanide (CN-) shall not exceed the following levels in the filtrate portion of a 5/1 extraction.

        1. 90 percent of at least 10 samples shall contain less than 5 mg/l free cyanide (CN-) in the filtrate.

        2. None of the samples shall contain more than 10 mg/l free cyanide (CN-) in the filtrate.

    e. For any sampling location that indicates a free cyanide level in excess of 10 mg/l in the filtrate, the areal extent of the inadequately detoxified area shall be determined and detoxified so that the cyanide levels in that particular ore pile will comply with the limitations contained in Specification No. 19 (d) 1 and 2, above.

20. Adjacent and contiguous ore piles or segments shall also be sampled simultaneously when any pile or segment is to be abandoned. If any additional processing is done in the sampled areas, the piles and segments tested will require additional rinsing and testing prior to abandonment.

21. The discharger shall maintain the monitoring system approved by the Executive Officer in writing, including ground water wells, vadose zone monitoring systems, and hydrostatic pressure sensors.

22. Specific locations of satellite leaching areas which are not within existing northern leach pad area or Section 16, shall be subject to review and approval by the Executive Officer.

23. At least 60 days[1] prior to commencement of construction of each component of the facility, the discharger shall submit to the Board, for approval by the Executive Officer a technical report which shall include a plan showing in detail the proposed construction of that component.

24. At least 10 days prior to commencement of operations, the discharger shall submit to the Regional Board a certificate, signed by a California Registered Civil Engineer, stating that the pads, containment basins, leakage detection system, flood protection and attendant facilities, and disposal areas are constructed in accordance with the technical report as approved by the Executive Officer to meet the requirements of this Order.

25. At least 10 days prior to loading ore onto the pads, the discharger shall notify the Board to allow sufficient time to schedule a staff evaluation of construction and inspection procedures utilized by the discharger for liner installation.

26. Prior to any significant modifications in this facility which could result in material change in the wastes discharged, or any material change in location of discharge, the discharger shall report in writing to the Regional Board, allowing sufficient time for Board consideration and action.

27. The discharger shall submit to the Regional Board, at least 30 days prior to commencement of the herein stated expanded operations, written adequate assurance that money is committed in an amount sufficient to insure detoxification of all cyanide, plus cleanup and closure of the processing and tailings disposal site upon abandonment of facilities, in a manner that will not adversely affect water quality. If the discharger presumes that the expanded operations should not require significant change in the amount of funds previously set aside, the discharger may submit a letter for the Regional Board Executive Officer's consideration, stating that a change is not warranted.

28. The discharger shall install devices in each new ore pile to measure solution depth (hydraulic head) above the liner.

---

[1] 60 days unless a lesser period is approved by the Executive Officer.

29. The discharger shall install a device for testing the leak detection system of each double-lined containment basin. Said testing shall be subject to approval by the Executive Officer.

B. Provisions

1. The discharger shall comply with "Monitoring and Reporting Program No. 89-034" and future revisions thereto, as specified by the Executive Officer.

2. Lack of construction or operational activity on the site for a period of one year shall constitute abandonment for the purpose of this Order.

IT IS FURTHER ORDERED that Board Order No. 87-44 be superseded by this Order.

I, Phil Gruenberg, Executive Officer, do hereby certify the foregoing is a full, true and correct copy of an Order adopted by the California Regional Water Quality Control Board, Colorado River Basin Region, on May 17, 1989.

Philip A Gruenberg
Executive Officer

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
COLORADO RIVER BASIN REGION

MONITORING AND REPORTING PROGRAM NO. 89-034
FOR
GOLD FIELDS OPERATING CO. - MESQUITE
Northeast of Glamis - Imperial County

Location of Discharge: Sections 3, 4, 5, 6, 7, 8, 9, 10, 15, 16, 17, 18, 19 & 20, T13S, R19E, SBB&M

MONITORING

Gold Fields Operating Co. - Mesquite (discharger) shall report to the Regional Board concerning the following:

Monitoring and Reporting No. 1

The discharger shall submit to the Regional Board monthly reports containing the following:

A. The current status of mining operations as to whether the operation is active or inactive.

B. An estimate of the total amount of ore (tons) presently being processed.

C. The amount of liquid collected in each seepage detection sump and the period of time since the last evacuation.

D. Analysis for free cyanide and total cyanide in ground water from each ground water monitoring well, and of any water found in each seepage detection sump.

E. Analysis for free cyanide and total cyanide for any liquid found in the vadose zone monitoring system.

Monitoring and Reporting No. 2

A. Immediate reporting of any accidental spillage, leakage, or release of waste material, including immediate measures being taken to correct same and limit detrimental effects.

B. Upon request from this Regional Board's Executive Officer, the discharger shall furnish special technical and/or monitoring reports on the treatment and discharge of wastes, and on the integrity of the cyanide solution containment system.

C. The discharger shall submit quarterly reports showing present and planned drainage parameters. These drainage parameters shall show compliance with Discharge Specifications A-9 and A-10 of this Board Order.

D. At least 30 days prior to any proposed abandonment of leached ore residues or discharge of wastewater, or termination of the operation described in this Order, the discharger shall submit a copy of the results of analyses of the cyanide concentration in the leached ore residue and in the wastewater in accordance with Discharge Specification No. 19, and shall request a Regional Board staff inspection to approve the proposed discharge or cleanup procedure.

E. Report of completion of cleanup of premises shall be submitted to the Regional Board in writing within one week following completion of work.

The above monitoring program shall be implemented and/or maintained immediately upon adoption of Order No. 89-034.

Quarterly reports shall be submitted to the Regional Board by January 15, April 15, July 15 and October 15 of each year. Monthly reports shall be submitted to the Regional Board by the 15th day of the following month. Reports for Item 2A. (above) shall be forwarded immediately and if at all possible shall be preceded by phone communication to the Regional Board's office. Phone No. (619) 346-7491. Copies of the report submitted to the Board pursuant to this Monitoring and Reporting Program shall be maintained at the operations site, and shall be made available to staff of the Regional Board upon request.

Mail Reports to:

California Regional Water Quality Control Board
Colorado River Basin Region
73-271 Highway 111, Suite 21
Palm Desert, CA 92260

ORDERED BY: Executive Officer

May 17, 1989
Date

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
COLORADO RIVER BASIN REGION

ATTACHMENT A TO ORDER NO. 89-034

ANALYTICAL PROCEDURE
FOR
IONIC CYANIDE
Also known as free soluble cyanide

Description: Ionic cyanide and most weak complexes are soluble in distilled water. The strong complexes of ions, although normally soluble, are bound too tightly to the particle surface and are not solubilized. The sample is leached with distilled water in a single pass, flow-through manner. The leachate is collected, alkalized for preservation, and made up to a definite volume. This leachate sample is then analyzed via "Standard Methods" 412 C or E. Method 412 D may not be used.

Apparatus:

1) Large glass funnel, the stem throat plugged with glass wool;

2) Large glass funnel with glass fiber filter paper: Whatman GF/C,934-AH, or equivalent.

3) Balance capable of weighing to nearest 0.01 g.

4) 500 ml volumetric flasks.

5) Items necessary to perform cyanide analysis as described in narrative above.

Reagents:

1) 2.5 N NaOH (100 g NaOH/l)

2) Reagents necessary to perform cyanide analysis as described in narrative above.

Procedure:

Weigh out, to nearest 0.01 g, 100±1 g of samples as received. Place in glass funnel, either glass wool plugged or with filter paper. Add 50.00 ml of 2.5 N NaOH to 500 ml volumetric flask and place it so as to catch the filtrate from the funnel. Pour 50 ml of distilled (or deionized) water onto the solid sample and allow to percolate through. When liquid level is even with the top of the of the solids, add an additional 50ml of water. Repeat the addition of water until a total of 400 ml H_2O has been used. Make up volume in volumetric flask to mark with distilled water. This constitutes the sample ready for analysis.

The titrametric (412C) and the ion selective probe (412E) require no further preparation. The sample is then read directly by either titrametric (412C) or the ion selective probe (412E) and the results reported in mg/l (CN-)

APPENDIX B

EXCERPTS FROM USGS STUDIES

B.1 PRELIMINARY APPRAISAL OF GROUND WATER IN STORAGE WITH REFERENCE TO GEOTHERMAL RESOURCES IN THE IMPERIAL VALLEY AREA, CALIFORNIA

(DUTCHER, ET AL., 1972)

B.2 GEOHYDROLOGIC RECONNAISSANCE OF THE IMPERIAL VALLEY, CALIFORNIA

(LOELTZ, ET AL., 1975)

APPENDIX B.1

PRELIMINARY APPRAISAL OF GROUND WATER IN STORAGE WITH REFERENCE TO GEOTHERMAL RESOURCES IN THE IMPERIAL VALLEY AREA, CALIFORNIA

(DUTCHER, ET AL., 1972)

PRELIMINARY APPRAISAL OF GROUND WATER IN STORAGE WITH REFERENCE TO GEOTHERMAL RESOURCES IN THE IMPERIAL VALLEY AREA, CALIFORNIA

U.S. DEPARTMENT OF THE INTERIOR

MARCH 3, 1849

GEOLOGICAL SURVEY CIRCULAR 649

Prepa [illegible] co [illegible] with the U.S. Bureau of Reclamation

Preliminary Appraisal of Ground Water in Storage With Reference to Geothermal Resources in the Imperial Valley Area, California

By L.C.Dutcher, W.F.Hardt, and W.R.Moyle, Jr.

GEOLOGICAL SURVEY CIRCULAR 649

Prepared in cooperation with
the U.S.Bureau of Reclamation

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ENVIRONMENTAL SOLUTIONS, INC

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COVER. Photograph courtesy of the Imperial Irrigation District.

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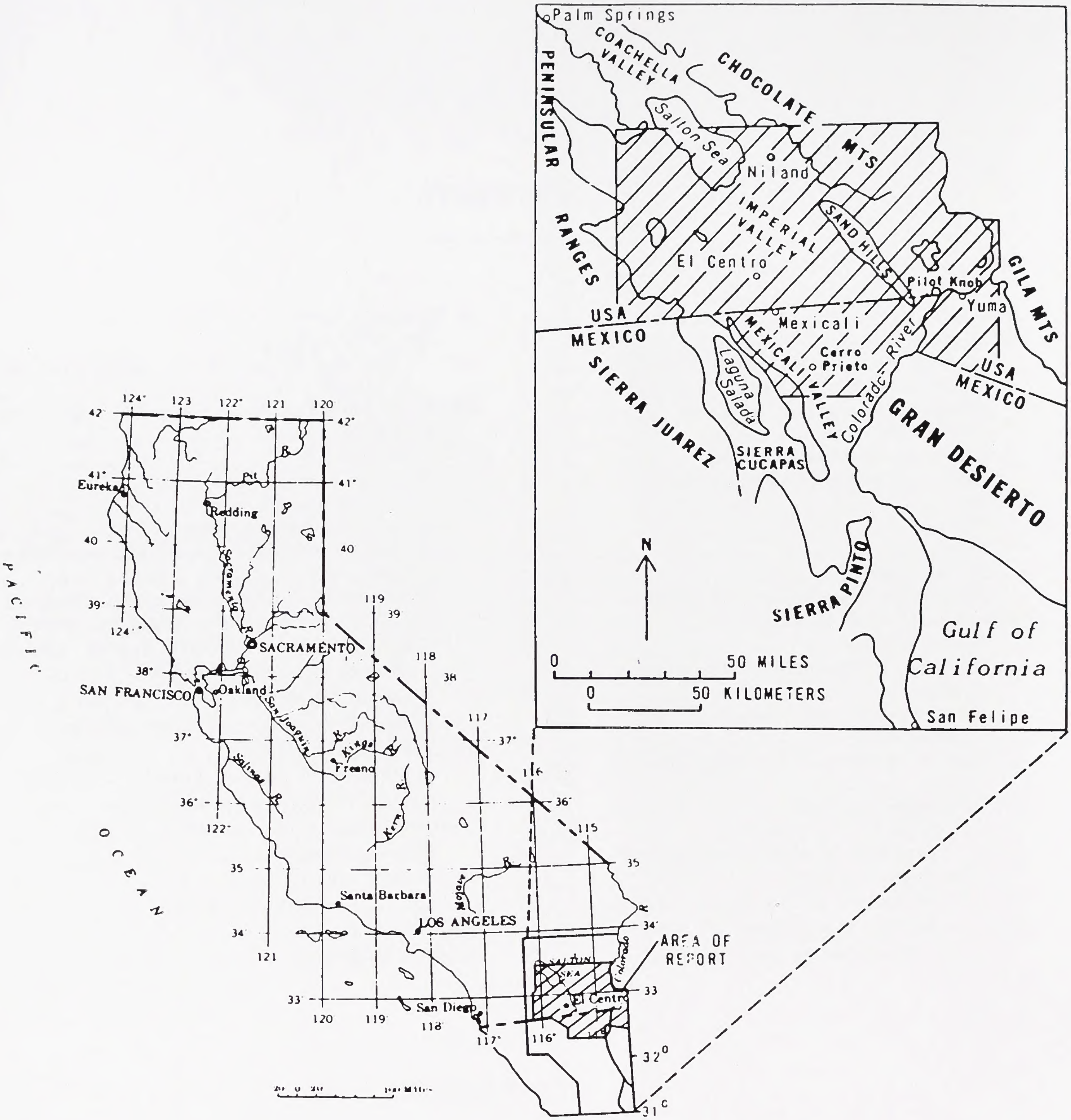
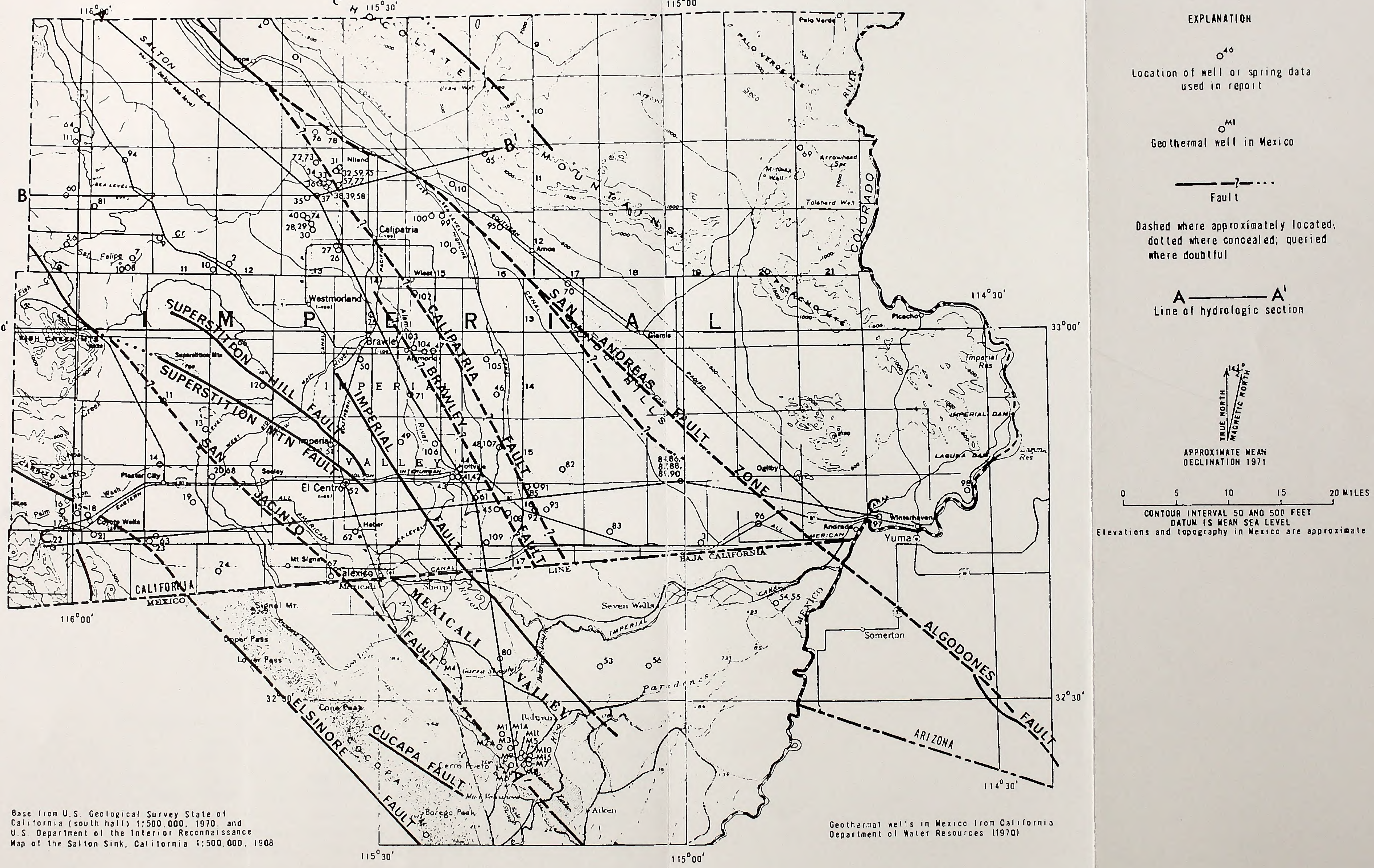


Figure 1.—Index map.

Nevertheless, the large deep structural basin filled with low to moderately permeable rocks having substantial porosity and therefore containing a substantial quantity of water in an area of higher than average heat flow has created widespread interest in the Salton Trough geothermal basin. Research and exploration of the gothermal, water, and chemical resources of the basin are being continued by public and private agencies. The goal is to determine the extent and value of the resources and the technical means of their economic use.



Base from U.S. Geological Survey State of California (south half) 1:500,000, 1970, and U.S. Department of the Interior Reconnaissance Map of the Salton Sink, California 1:500,000, 1908

Geothermal wells in Mexico from California Department of Water Resources (1970)

FIGURE 2.—Continued.

FIGURE 2.—Location of wells, springs, and hydrologic sections in Imperial and Mexicali Valleys.

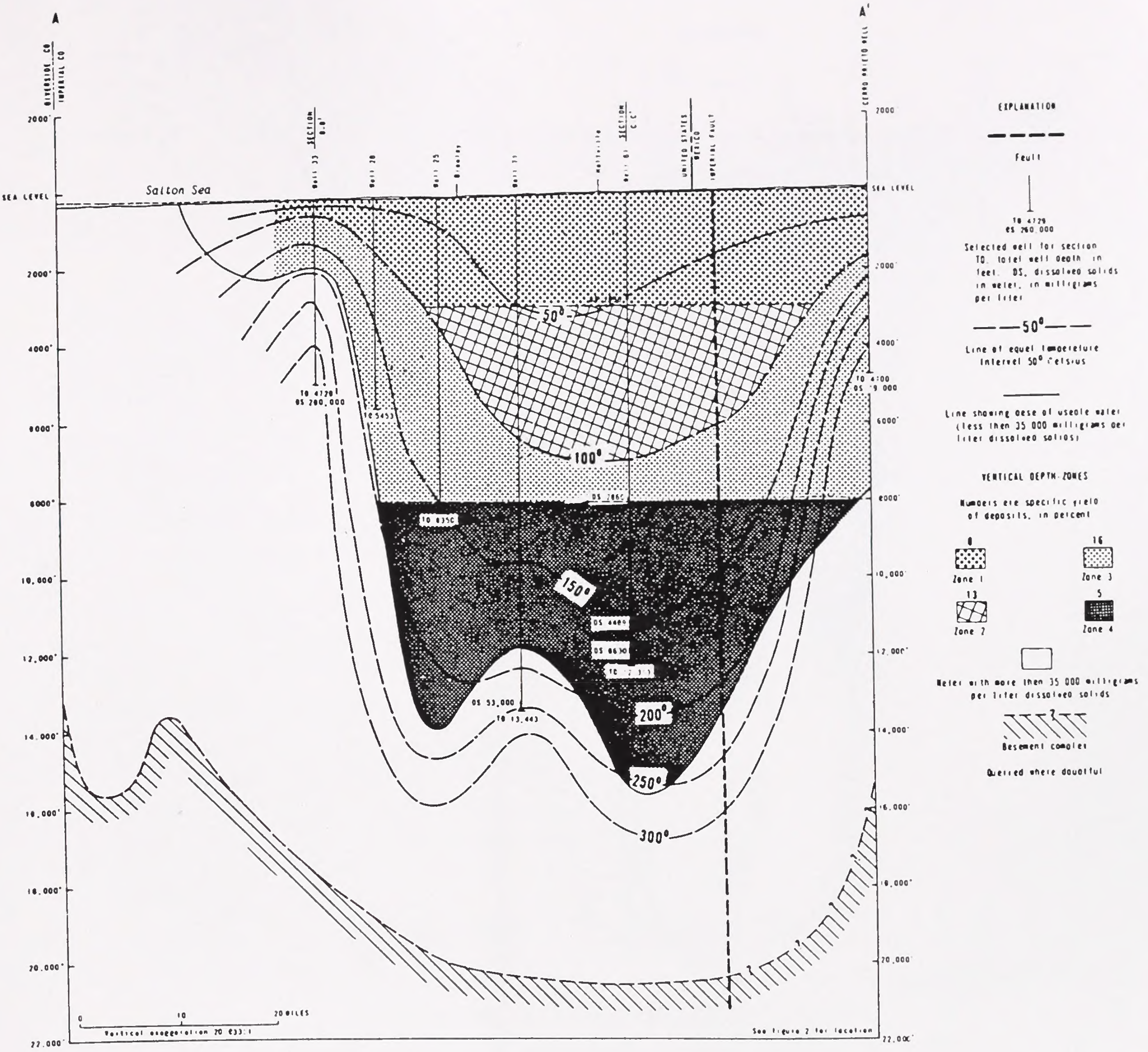

A
A'
Salton Sea
SEA LEVEL
2000'
4000'
6000'
8000'
10,000'
12,000'
14,000'
16,000'
18,000'
20,000'
22,000'
50°
100°
150°
200°
250°
300°
TD 4729
DS 260,000
EXPLANATION
Fault
Selected well for section TD, total well depth in feet. DS, dissolved solids in water, in milligrams per liter
Line of equal temperature Interval 50° Celsius
Line showing base of useable water (less than 35 000 milligrams per liter dissolved solids)
VERTICAL DEPTH ZONES
Numbers are specific yield of deposits, in percent
8
Zone 1
16
Zone 3
13
Zone 2
5
Zone 4
Water with more than 35 000 milligrams per liter dissolved solids
Basement complex
Queried where doubtful
Vertical exaggeration 20 times
See figure 2 for location

FIGURE 9.—Hydrologic section *A–A'*.

At the Salton Sea hydrothermal field, the geothermal gradient in zone 1 (in the deposits extending to a depth of about 3,000 ft below the surface) averages nearly 10°C per 100 feet (fig. 6). In that entire zone heat flux is probably dominated by conduction. At depths greater than 3,000 feet heat flux is probably dominated by convection. At Cerro Prieto the geothermal gradient in zone 1 (the deposits extending to about 2,400 ft below the surface) also averages about 10°C per 100 feet and heat flow is also probably dominated by conduction in those deposits; at depths greater than 2,400 feet heat flow is probably dominated by convection.

At well 85 (U.S. Bur. Reclamation well 116) southeast of Holtville the average geothermal gradient in zone 1 (only 1,400 ft tested) averages about 7°C per 100 feet, in a zone where conduction presumably dominates.

In the areas outside the known hot spots, in most of the system, all available data indicate that in zones having heat flux probably dominated by conduction, geothermal gradients range from less than 1°C per 100 feet across some thick zones to as much as 2° or 3°C per

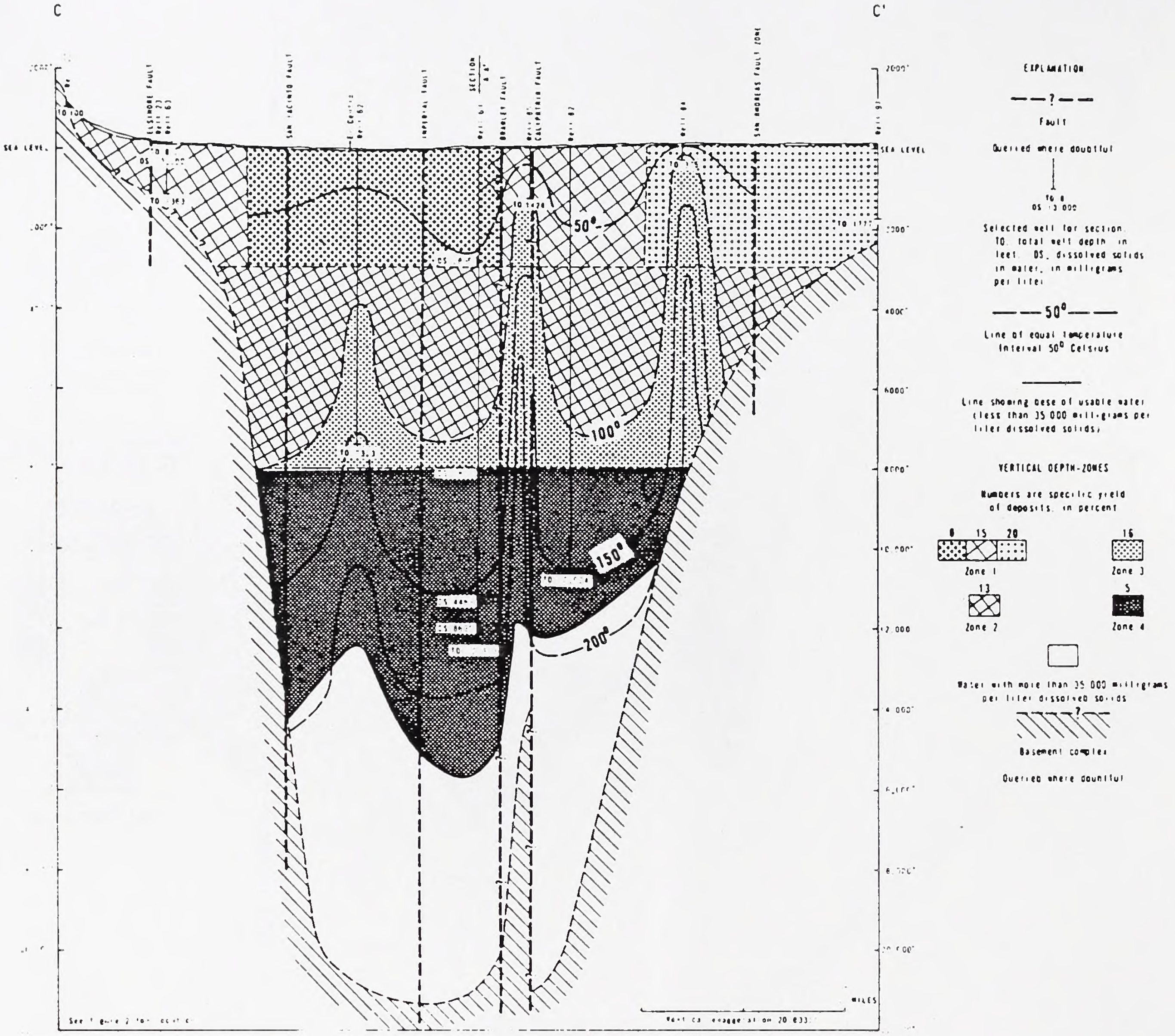

C
C'
SEA LEVEL
2000'
4000'
6000'
8000'
10,000'
12,000'
14,000'
50°
100°
150°
200°
San Jacinto Fault
Imperial Fault
San Andreas Fault Zone
MILES
EXPLANATION
Fault
Queried where doubtful
TD 0
DS 13 000
Selected well for section. TD, total well depth, in feet. DS, dissolved solids in water, in milligrams per liter
50°
Line of equal temperature. Interval 50° Celsius
Line showing base of usable water (less than 35 000 milligrams per liter dissolved solids)
VERTICAL DEPTH-ZONES
Numbers are specific yield of deposits, in percent
8
15
20
Zone 1
16
Zone 3
13
Zone 2
5
Zone 4
Water with more than 35 000 milligrams per liter dissolved solids
Basement complex
Queried where doubtful

FIGURE 11.—Hydrologic section *C–C'*.

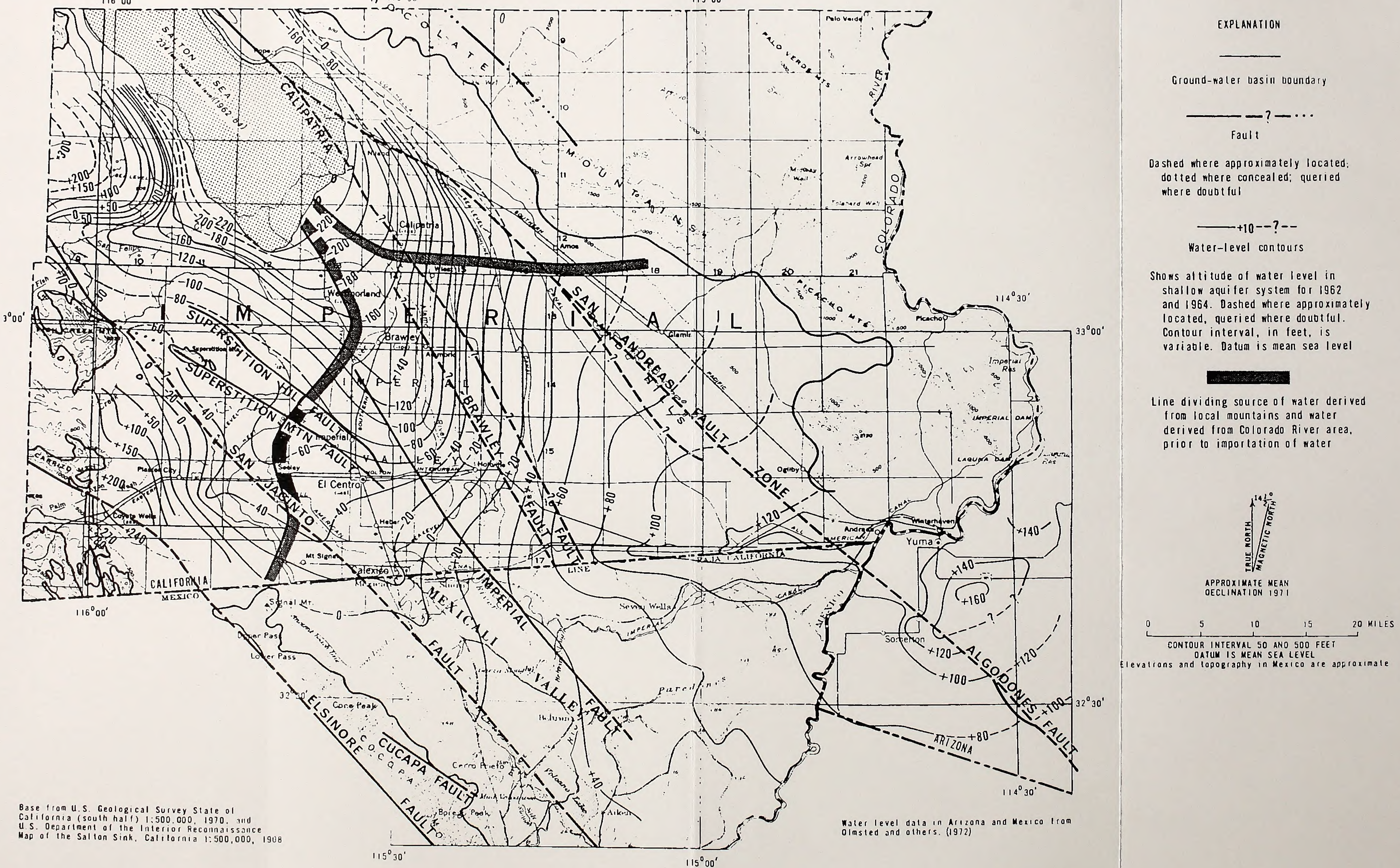
a depth only slightly greater than that reached by the drill.

At well 61, southeast of Holtville, a deep convection cell probably exists at a depth several thousand feet deeper than that reached by the drill.

Within the convection cells at the Salton Sea and Cerro Prieto fields, the temperature gradients are much lower than where the heat flux is dominantly by conduction (fig. 6). Presumably the temperatures of the upflowing fluids throughout the cell are only slightly below the reference boiling-point curve for the brine solution analyzed. The temperature is slightly below the reference curve probably because of partial pressures of gasses in the system (fig. 6).

THE DYNAMIC SYSTEM

Most basic elements and mechanisms of the Imperial Valley area hydrothermal system cannot yet be measured directly. A satisfactory conceptual model of the system must represent the mechanisms and elements of the prototype, insofar as the available data permit the system to be understood. The mechanisms proposed for the system must be compatible not only with available data but also with principles of chemistry and physics.

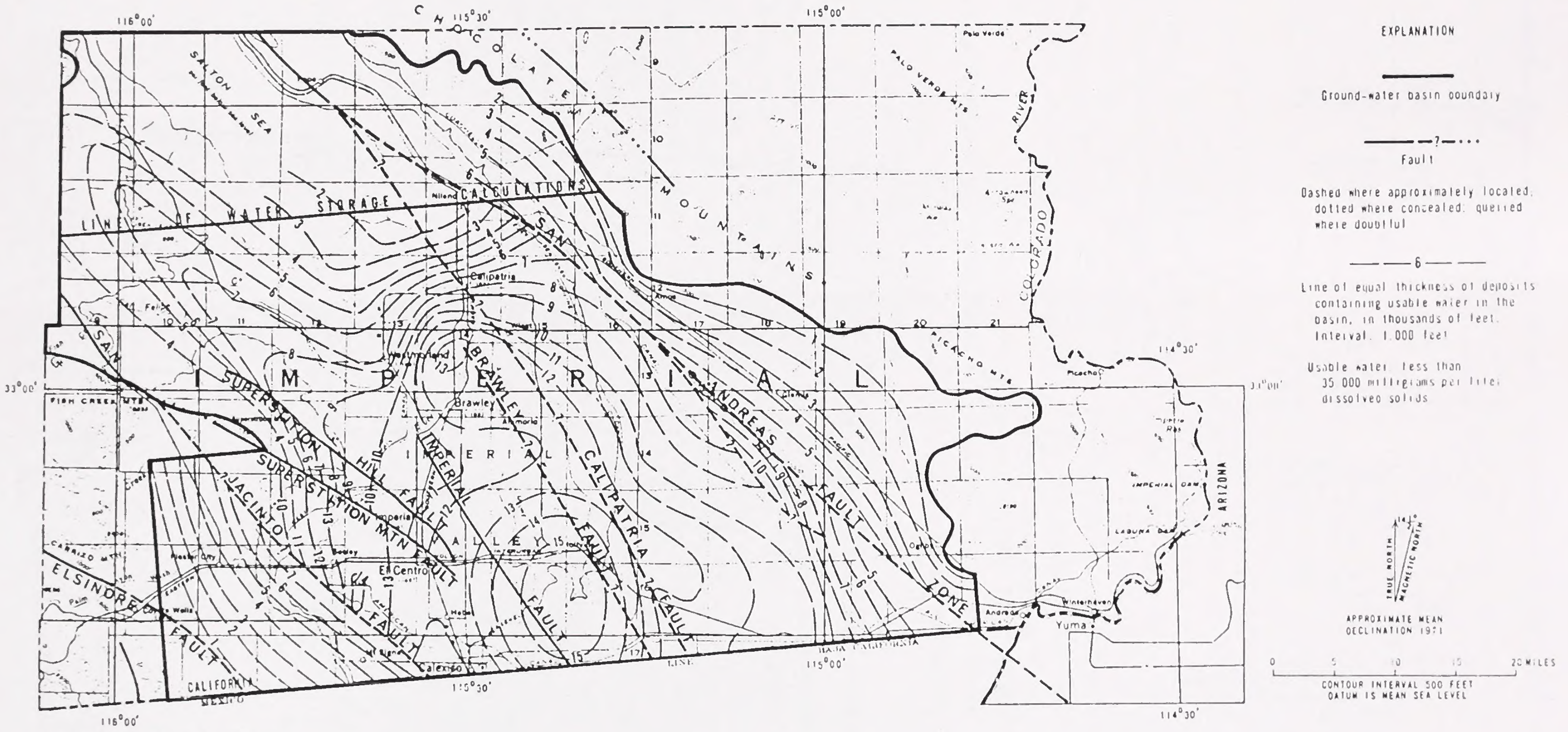


Base from U.S. Geological Survey State of California (south half) 1:500,000, 1970, and U.S. Department of the Interior Reconnaissance Map of the Salton Sink, California 1:500,000, 1908

Water level data in Arizona and Mexico from Olmsted and others (1972)

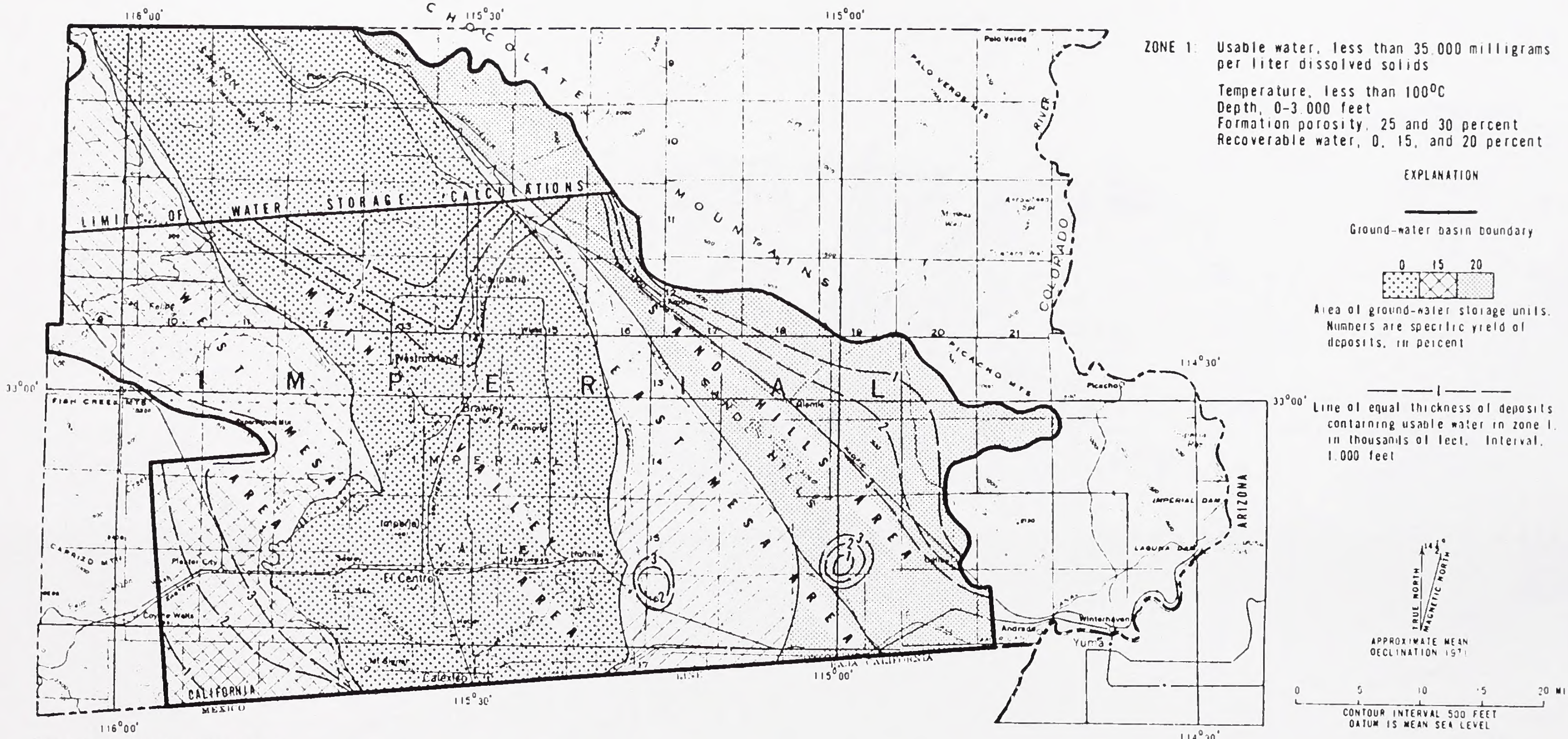
FIGURE 13.—Ground-water-level contours of shallow aquifer system, 1962 and 1964, in Imperial and Mexicali Valleys.

FIGURE 13.—Continued.



Base from U.S. Geological Survey State of California (south half) 1:500 000 1970

FIGURE 15.—Thickness of deposits with total usable water.



Base from U.S. Geological Survey State of California (south half) 1:500,000, 1970

FIGURE 16.—Thickness of deposits with usable water in zone 1.

TABLE 2.—*Usable and recoverable water at temperature of 150°C or more*

[Estimates in millions of acre-feet]

Source	Storage in areal subunits				Rounded total	Percentage of total
	Sand Hills	East Mesa	Main valley	West Mesa		
Colorado River	10	48	69	0	127	64
Local	.91	2.9	60	5.6	70	36
Rounded total	11	51	129	5.6	197	—

directly from the canals that drain the irrigated land.

The area of the Sand Hills subunit is about 450 sq mi, that of the East Mesa subunit about 350 sq mi, and that of the West Mesa subunit about 465 sq mi. About 350 million acre-feet of usable and recoverable water is contained in zone 1 (see table 3).

WATER AT TEMPERATURES MORE THAN 150°C

The areal extent of usable water at a temperature more than about 150°C is shown in figure 20. Such water is widespread; we believe it underlies almost all of the Imperial Valley area and is absent only along the marginal parts of the valley beneath strips of land a few to 10 or more miles wide. The thickness of rocks containing usable water at 150°C or more ranges from 0 to more than 8,000 feet. The estimated average porosity of the reservoir rock is about 10 percent.

Figure 20 shows the thickness of four known areas with deposits containing usable hot water at more than 150°C. Southeast of Holtville the deposits are more than 8,000 feet thick, near Heber about 5,000 feet thick, and near both Ogilby and Westmoreland about 6,000 feet thick. In much of the area, however, the thickness of deposits with usable water at a temperature of 150°C or greater is only 1,000–2,000 feet.

The total estimated usable water in storage having a temperature of 150°C or more (table 2) is rounded to about 200 million acre-feet.

On the basis of the data available regarding the probable source of the water, about 64 percent or about 127 million acre-feet is derived from the Colorado River, and 36 percent or about 70 million acre-feet is from local sources.

SUMMARY OF USABLE AND RECOVERABLE WATER

Preliminary estimates of total usable and recoverable water in storage are summarized in table 3. Total usable and recoverable water in storage is estimated to be 1.1 billion acre-feet. This compares to a quantity in storage of 1.6–4.8 billion acre-feet previously estimated by Rex (1970, p. 14). Of that amount, about 190 million acre-feet is contained in the four vertical depth zones beneath the Sand Hills storage unit (fig. 16), about 280 million acre-feet underlies the East Mesa area, about 430 million acre-feet is beneath the main valley irrigated area, and about 215 million acre-feet is beneath the West Mesa area.

TABLE 3.—*Summary of usable and recoverable water in the Imperial Valley area, California, containing less than 35,000 mg/l dissolved solids*

[Estimates in millions of acre-feet]

Vertical depth zone	Storage in areal subunits					Percentage in each depth zone
	Sand Hills	East Mesa	Main valley	West Mesa	Total	
1	126	103	0	120	349	31
2	28	89	181	63	360	32
3	38	67	170	29	304	28
4	.1	19	77	2.4	99	9
Rounded total	190	280	430	215	1,100	—
Percentage in each areal subunit	17	25	39	19	100	

TABLE 4.—*Summary of usable and recoverable water in storage derived from the Colorado River and local sources*

[Estimates in millions of acre-feet]

Vertical depth zone	Storage in areal subunits				Total	Percentage in each depth zone
	Sand Hills	East Mesa	Main valley	West Mesa		
Zone 1:						31
Local	16	6	0	119	141	
Colorado River	110	97	0	.9	208	
Zone 2:						32
Local	2.6	4.7	75	63	145	
Colorado River	25	84	106	0	215	
Zone 3:						28
Local	5.3	4.8	68	29	107	
Colorado River	32	63	102	0	197	
Zone 4:						9
Local	0	0	24	2.4	26	
Colorado River	.1	19	53	0	72	
Totals:	191	279	428	214	1,112	—
Local	24	16	167	213	420	38
Colorado River	167	263	261	.9	692	62
Percentage of total:						
Local	13	6	39	100	38	
Colorado River	87	94	61	0	62	

The vertical distribution (fig. 9) of the usable and recoverable water in storage is about as follows: vertical depth-zone 1 (from the water table to a depth of 3,000 ft in most of the area), about 350 million acre-feet; depth-zone 2 (from 3,000 ft to a water-temperature depth of 100°C in most of the area), about 360 million acre-feet; depth-zone 3 (from a water-temperature depth of 100°C to a depth of 8,000 ft in most of the area), about 300 million acre-feet; and depth-zone 4 (at a depth greater than 8,000 ft), about 100 million acre-feet.

Preliminary estimates of total usable and recoverable water in storage derived from local sources and the Colorado River are summarized in table 4. Of the approximate total 1.1 billion acre-feet in storage, about 420 million acre-feet or about 38 percent was probably derived from local sources and about 690 million acre-feet or about 62 percent was probably derived from the Colorado River.

RELIABILITY OF THE ESTIMATES

The probable percentage error for the estimates compiled in this report cannot be determined. Data are not available on which such error estimates could be based. In fact, if it had been required at this stage that such estimates be based on standard methods of computation, using only data that would ordinarily be termed of minimum acceptable accuracy, in the amount ordinarily acceptable, and having the usually required pattern of distribution throughout the system, it would have been impossible to compile the estimates.

The logic on which the great extrapolations could be based had to be developed by formulating a conceptual model of the sedimentary basin, considering the elements and mechanisms of the hydrothermal system. Both models had to take into consideration all available data and information available at the present time (June 1971). Therefore, the accuracy of the estimates of usable and recoverable water in storage in the system is directly related to how adequately the conceptual model of the system represents the prototype. How nearly the conceptual model agrees with the prototype cannot be determined until considerable additional data are collected and much further research is completed. Until additional data are generated and much new research is done, the estimates must be considered usable engineering approximations; all planning, including development of the resources, research, and future data-collection programs, should be based on that understanding.

SIGNIFICANCE OF PRODUCTION METHODS

Although the estimates of recoverable water (tables 2, 3, and 4) in the Imperial Valley area were based on an assumption that all water in

APPENDIX B.2

GEOHYDROLOGIC RECONNAISSANCE OF THE IMPERIAL VALLEY, CALIFORNIA

(LOELTZ, ET AL., 1975)

Geohydrologic Reconnaissance of the Imperial Valley, California

By O. J. LOELTZ, BURDGE IRELAN, J. H. ROBISON, *and*
F. H. OLMSTED

WATER RESOURCES OF LOWER COLORADO RIVER–SALTON SEA AREA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 486–K

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1975

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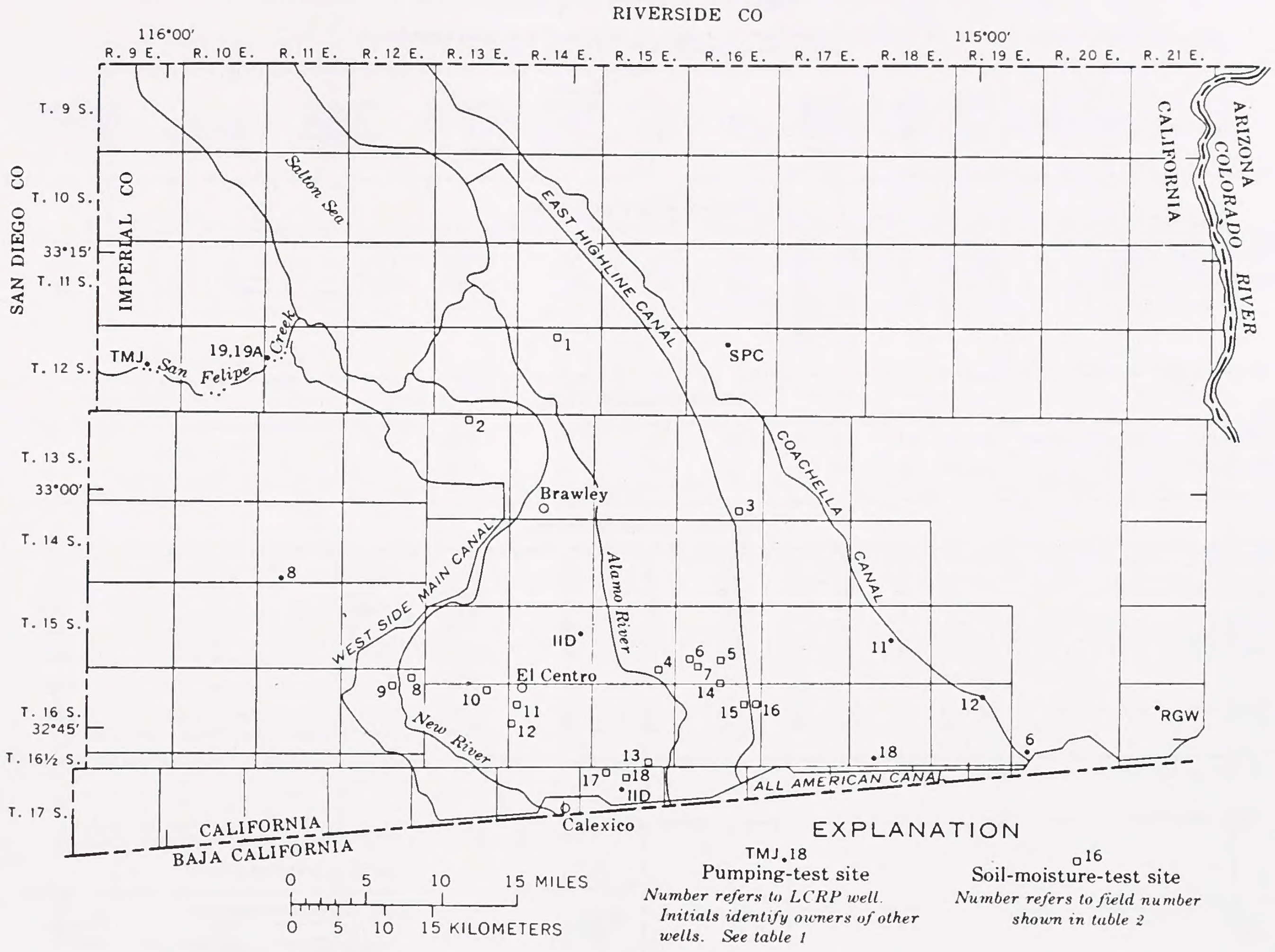


FIGURE 7. — Location of pumping-test and soil-moisture-test sites.

SOIL-MOISTURE STUDIES

The moisture content of soil profiles was determined at 18 sites in Imperial Valley (fig. 7). A neutron probe was lowered inside access holes of 1.62-inch ID steel tubing, generally driven to depths of about 16 feet below the land surface, and a counting rate was determined at 1-foot intervals. From the counting rate the moisture content of the material at a particular depth was determined on the basis of the relation shown in figure 8. This relation was inferred from specific relations between laboratory determinations of moisture content or porosity of samples and the respective counting rate obtained with the soil-moisture meter for the samples in the field; it is valid only for the conditions under which the data were obtained. Experiments during this study showed that the relation changes if different methods are used for installing the tubing or if other kinds and diameters of tubing are used. Figure 9 shows graphs of the counts per minute that were obtained with the soil-moisture meter at different depths below the land surface at several sites in the valley. In the zone of saturation — that is, below the water table — the rate generally is 7,000 to 8,000 counts per minute, which corresponds to a moisture content of 41 to 48 percent by volume of the material. The high counting rate sometimes persists for several feet above the water table, which indicates that the lower part of the capillary fringe is saturated or nearly saturated. At three of the sites the counting rate was 1,000 or less per minute for a part of the depth tested. The low counting rate is related to the slight moisture content of the material above the capillary fringe; 1,000 counts per minute corresponds to a moisture content of somewhat less than 5 percent.

The difference between the average moisture content of the saturated material and that of the material above the capillary fringe is an estimate of the quantity of water that will go into storage per unit volume of material as water levels rise in an area where the capillary fringe does not reach the land surface. Table 2 lists the moisture content below the water table and above the capillary fringe and the difference between these contents at each site where

TABLE 1. — *Results of pumping tests*

[Type of test: D, drawdown; R, recovery. All wells completed in Quaternary alluvium. LCRP, Lower Colorado River Project of U.S. Geol. Survey]

Well (fig. 7)	Owner or name	Date of test	Type of test	Interval tested (ft below land surface)	Yield (gpm)	Draw-down (ft)	Specific capacity in gpm per foot of drawdown	Transmissivity computed from tests (gpd per ft)	Conformance of test data to theoretical values	Reliability of computed transmissivity	Indicated average field hydraulic conductivity (gpd per sq ft)
Western Imperial Valley											
12S/ 9E-22A2	T. M. Jacobs	7-29-63	R	285- 667	1,450	14	100	290,000	Excellent	Good	760
12S/11E-18J1	LCRP 19	5-20-64	R	310- 650	150	4	38	100,000	Fair	Fair	300
18J2	LCRP 19A	5-20-64	R	35- 55	45	8.5	5	37,000	do	do	1,800
14S/11E-32R	LCRP 8	5-11-62	R	135- 165 218- 258 310- 354 390- 416 430- 560	250	13	19	130,000	Good	Good	480
Central Imperial Valley											
15S/14E-18C	Imperial Irrigation District.	5-9-58	R	140- 440	160	86	2	2,200	Good	Good	7
17S/15E-10N	do	5-16-58	R	110- 450	90	68	1.3	1,700	do	do	5
Eastern Imperial Valley											
12S/16E-9A	Southern Pacific Co.	7-9-63	R	150-1,000	975	43	23	62,000	Excellent	Good	73
		7-9-63	D	150-1,000	675	27	25	47,000	Good	do	55
15S/18E-15M	LCRP 11	5-10-63	R	309- 894	1,000	20	50	220,000	do	do	380
		5-10-63	D	309- 894	1,000	20	50	220,000	Excellent	do	380
16S/18E-32R	LCRP 18	6-29-64	R	140- 630	900	21	43	140,000	do	do	240
16S/19E-11D	LCRP 12	5-14-63	R	300- 610	990	24	41	240,000	Good	do	770
16S/20E-31K	LCRP 6	5-2-62	R	340- 410 510- 520	1,035	12	85	850,000	Excellent	do	10,000
		5-2-62	D	340- 410 510- 520	1,035	12	85	880,000	Good	do	10,000
16S/21E-16B	R. G. Winder	12-4-62	R	598- 806	1,550	36	43	[1]630,000	Poor	Poor	3,000
		12-4-62	D	598- 806	1,550	36	43	[1]590,000	do	do	2,800

[1] May be too high by a factor of 2.

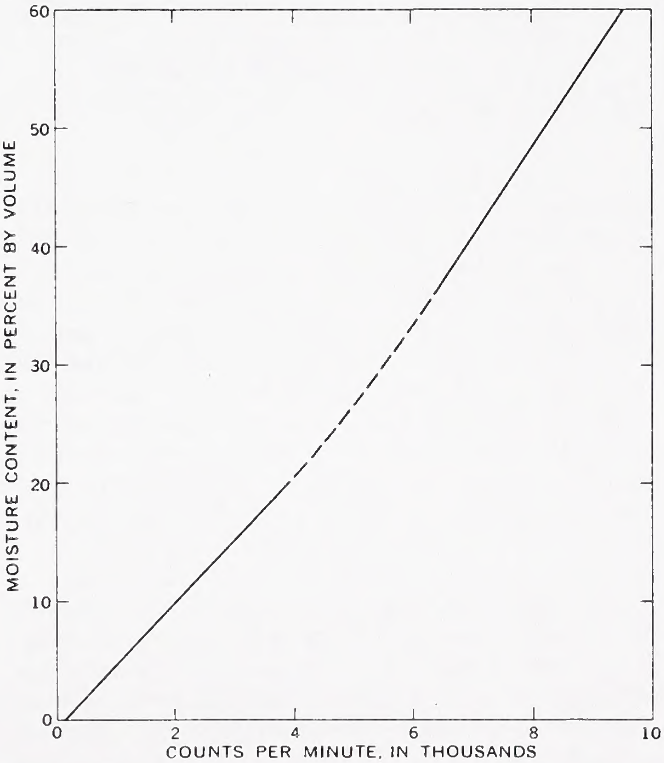


FIGURE 8. — Relation between counts per minute obtained with the soil-moisture meter and moisture content of the soil. The line is dashed where the relation was not determined for this study.

TABLE 2. — *Moisture content and storage capacity of alluvium*

[All quantities in percent by volume]

Field No. (fig. 7)	Location	Average moisture content		Storage capacity
		Below water table	Above capillary fringe	
1	12S/14E-4K	44	----	----
2	13S/13E-3E	45	----	----
3	13S/16E-35M	----	2	----
4	15S/15E-35A	41	----	----
5	15S/16E-27D	45	4	41
6	15S/16E-29D	44	----	----
7	15S/16E-29Q	44	----	----
8	16S/12E-1M	44	----	----
9	16S/12E-11E	43	----	----
10	16S/13E-2H	45	----	----
11	16S/14E-7K	43	----	----
12	16S/14E-19D	46	----	----
13	16S/15E-35P	41	----	----
14	16S/16E-3D	41	----	----
15	16S/16E-12P	44	----	----
16	16S/16E-12Q	43	3	40
17	17S/15E-5J	43	8	35
18	17S/15E-10C	44	----	----
	Average	43	4	39

such determinations were possible; the average for each of the determinations is also given.

The average moisture contents for deposits in the Imperial Valley compare favorably with moisture contents for flood-plain deposits in the other valleys in the lower Colorado River area in which similar studies were made. For example, at 11 sites in Parker Valley, Ariz., the average moisture content was 45 percent in the zone of saturation and 6 percent in the zone above the capil-

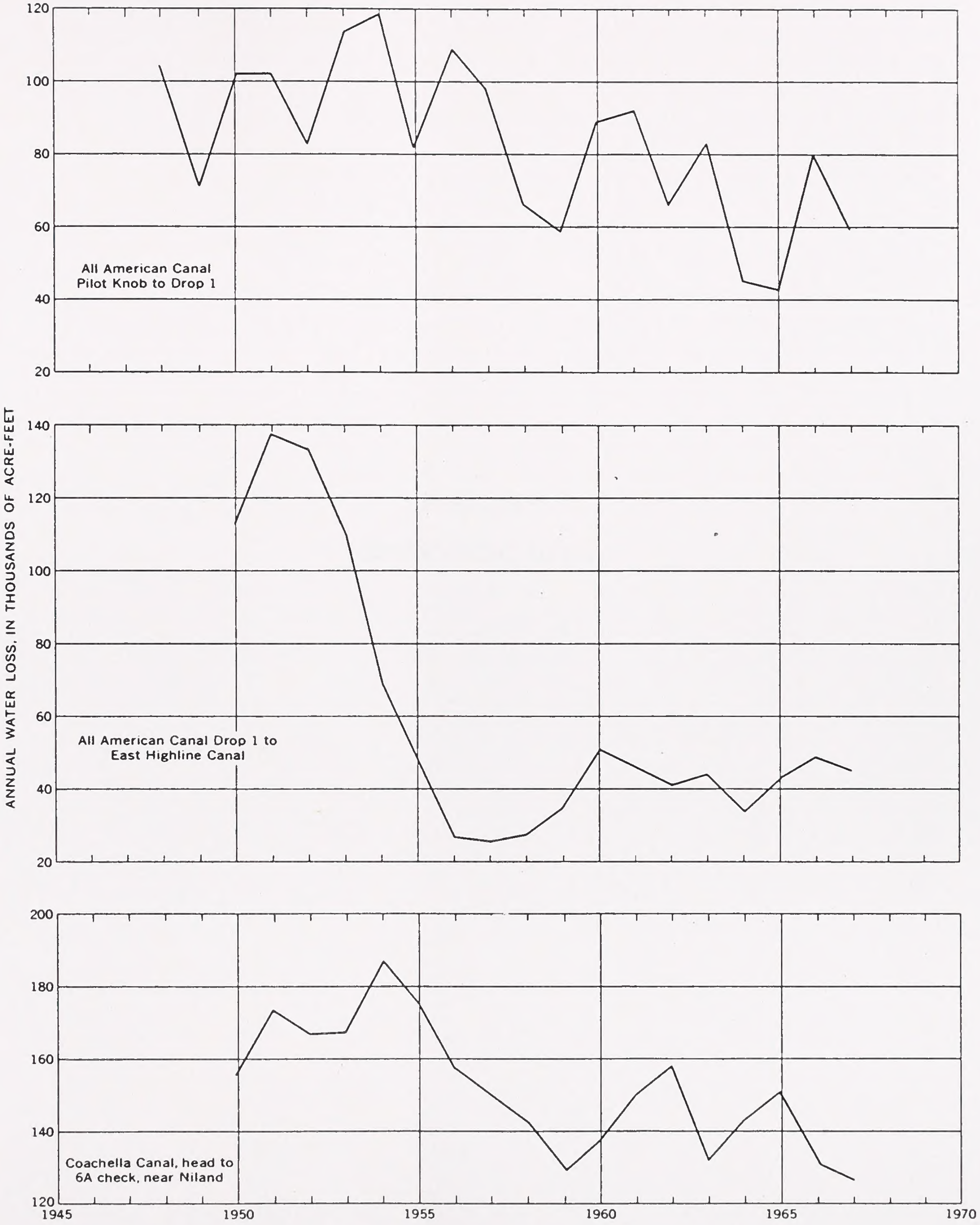
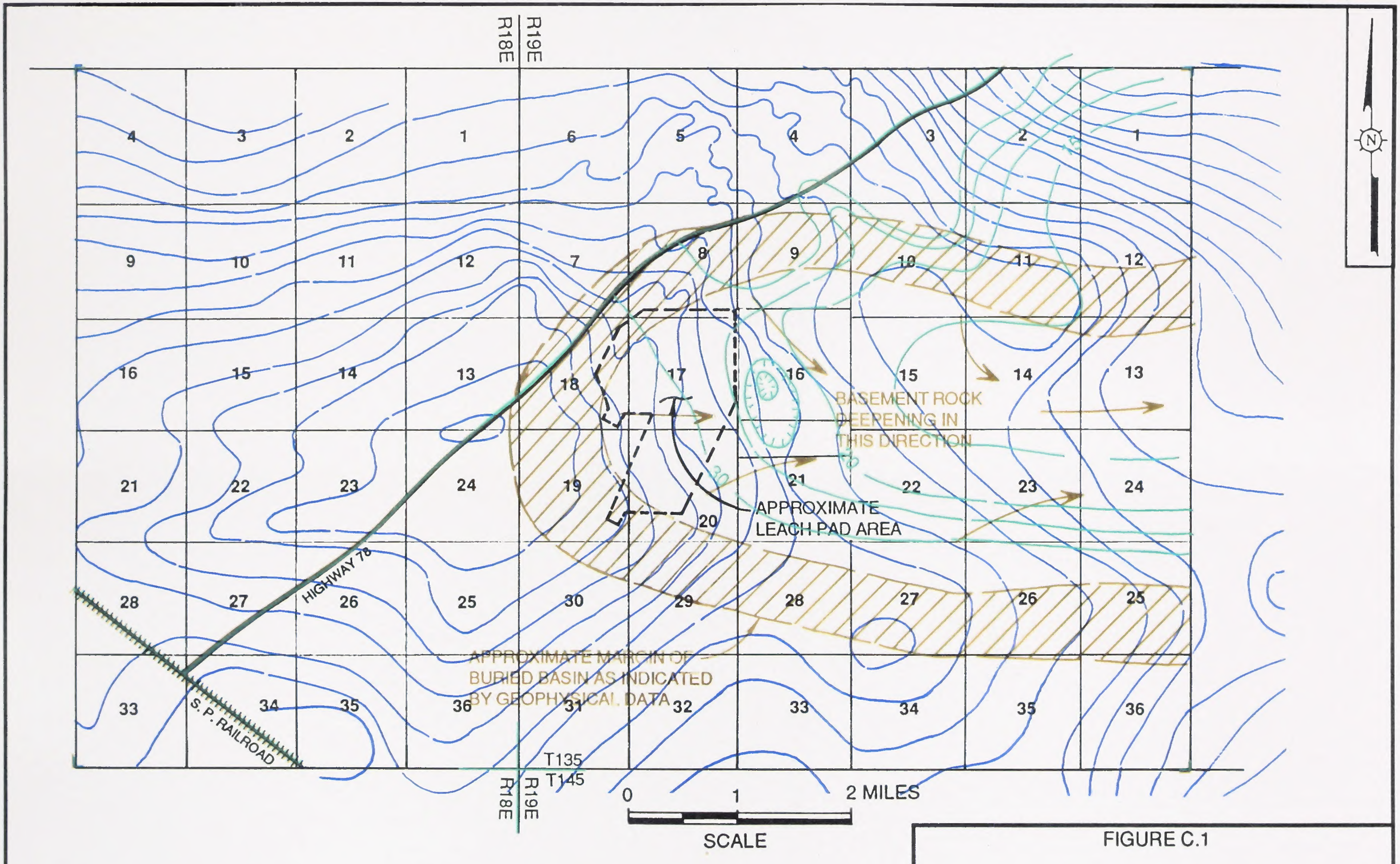


FIGURE 10. — Water losses in selected reaches of the All-American and Coachella Canals.

APPENDIX C

GEOPHYSICAL DATA

91-296 HAR REV. 9/22/92



SOURCE: GOLD FIELDS

FIGURE C.1

RESISTIVITY AND GRAVITY SURVEY DATA

MESQUITE REGIONAL LANDFILL

APPENDIX D

GOLD FIELDS' PRODUCTION AND MONITORING WELL LOGS

D.1 - GF-1 BORING LOG
D.2 - GF-2 BORING LOG
D.3 - GF-3A BORING LOG
D.4 - MBH-1 BORING LOG
D.5 - MBH-2 BORING LOG
D.6 - MBH-3 BORING LOG
D.7 - MCR-80 BORING LOG

APPENDIX D.1

GF-1 BORING LOG

McCalla Bros.

Well Drilling & Pump Sales

MAIN OFFICE
3819 West First Street
Santa Ana, California 92703
Phone 714 775 7714

BRANCH OFFICES
13855 Central Avenue
Chino, California 91710
Phone 714 627-1521

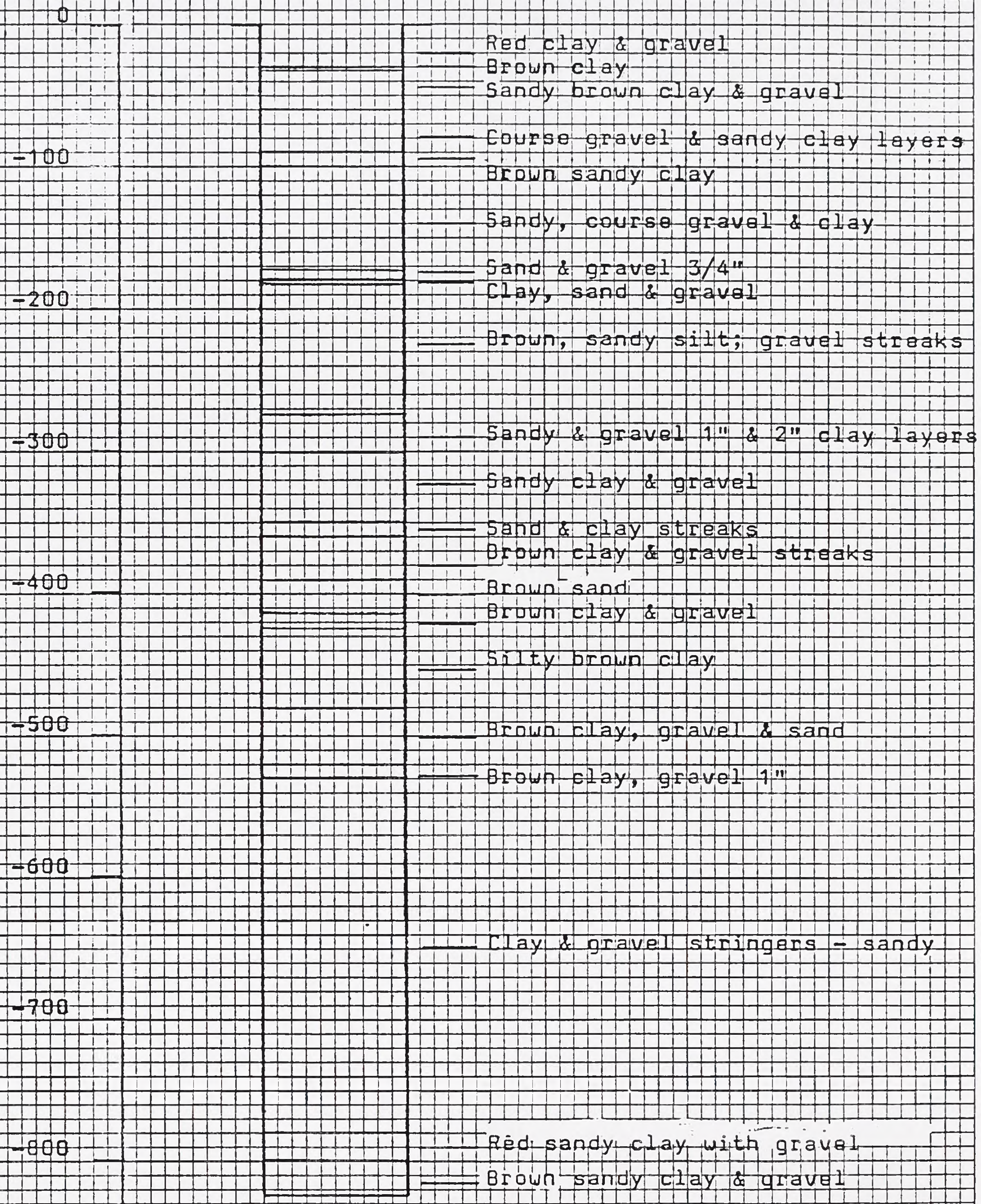
980 Nevada Street
Redlands, California 92373
Phone 714 793 2913

PHYSICAL WELL LOG

GOLD FIELDS MINING CORP. JOB NO. 6891

0 - 30'	Red clay & gravel
30 - 32'	Brown clay
32 - 60'	Sandy brown clay & gravel
60 - 90'	Coarse gravel & sandy clay layers
90 - 100'	Brown sandy clay
100 - 175'	Sandy, coarse gravel & clay
175 - 183'	Sand & gravel 3/4" (possible water)
183 - 185'	Clay, sand, & gravel
185 - 275'	Brown, sandy silt; gravel streaks
275 - 300'	Sandy & gravel 1" & 2" clay layers
300 - 350'	Sandy clay & gravel
350 - 360'	Sand & clay streaks
360 - 390'	Brown clay & gravel streaks
390 - 415'	Brown sand
415 - 425'	Brown clay & gravel
425 - 480'	Silty brown clay
480 - 520'	Brown clay, gravel, & sand (water level 490')
520 - 530'	Brwon clay, gravel 1" (hit water)
530 - 780'	Clay & gravel stringers - sandy
780 - 800'	Red sandy clay with gravel
800 - 822'	Brown sandy clay & gravel

NEW VISTA WELL
GRAPHIC WELL LOG


0
Red clay & gravel
Brown clay
Sandy brown clay & gravel
Course gravel & sandy clay layers
-100
Brown sandy clay
Sandy, course gravel & clay
Sand & gravel 3/4"
Clay, sand & gravel
-200
Brown, sandy silt; gravel streaks
Sandy & gravel 1" & 2" clay layers
-300
Sandy clay & gravel
Sand & clay streaks
Brown clay & gravel streaks
-400
Brown sand
Brown clay & gravel
Silty brown clay
-500
Brown clay, gravel & sand
Brown clay, gravel 1"
-600
Clay & gravel stringers - sandy
-700
-800
Red sandy clay with gravel
Brown sandy clay & gravel

46 0702

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

APPENDIX D.2

GF-2 BORING LOG

Coachella Valley Pump & Supply, Inc.
P. O. DRAWER QQQ • INDIO, CALIFORNIA 92202 • (619) 347-0741

DATE June 12, 1985
JOB NO.
ATTENTION Andy K
RE Production Well #2

TO Goldfield Mining Corporation
P.O Box 441
Brawely, Ca. 92227

GENTLEMEN:

WE ARE SENDING YOU ☒ Attached ☐ Under separate cover via ______ the following items:

☐ Shop drawings ☐ Prints ☐ Plans ☐ Samples ☐ Specifications

☐ Copy of letter ☐ Change order ☒ Well log and test on Well #2

COPIES	DATE	NO.	DESCRIPTION
1	April		Long term test and well log.

THESE ARE TRANSMITTED as checked below:

☐ For approval ☐ Approved as submitted ☐ Resubmit ______ copies for approval
☐ For your use ☐ Approved as noted ☐ Submit ______ copies for distribution
☒ As requested ☐ Returned for corrections ☐ Return ______ corrected prints
☐ For review and comment ☐ ______
☐ FOR BIDS DUE ______ 19______ ☐ PRINTS RETURNED AFTER LOAN TO US

REMARKS ______

COPY TO ______

D.2-1

SIGNED: Larry G. Mann by Jonette
Larry G. Mann President

If enclosures are not as noted, kindly notify us at once.

COACHELLA VALLEY PUMP & SUPPLY, INC.

SHOP WORK ORDER

JOB # Cable Tool Rig #1

JOB NAME Goldfields

DATE 11-22-84

DESCRIPTION OF WORK

Drill 16" hole to 800'

Driv and Eddie

LIST REPLACEMENT AND/OR ADDITIONAL PARTS NEEDED

E	QUANTITY		NEW	USED
11-22	4	Starter pipe		
11-23	1	12' 1"	91-1	
11-24	1	12' 1"	103-2	
11-25	1	12' 1"	115.3	
11-25	1	12' 1"	127.4	
11-25	1	4'	131.4	
11-26	1	4'	135.4	
11-26	1	4'	139.4	
11-27		Spudder arm repair day off.		
11-28	1	4'	143.4	
11-28	1	4'	147.4	
11-28	1	4'	151.4	
11-29	1	4'	155.5	
11-29	1	4'	159.5	
11-29	1	12' 1"	171.6	
11-29	1	12' 1"	183.7	
11-29	1	12' 1"	195.8	
11-30	1	12' 1"	207.9	
11-30	1	7' 9"	215.6	
11-30	1	8' ½"		

COACHELLA VALLEY PUMP & SUPPLY, INC.

SHOP WORK ORDER

JOB # Cable Tool Rig #1

JOB NAME Goldfields

DATE 11-22-84

DESCRIPTION OF WORK

Drill 16" hole to 800'

LIST REPLACEMENT AND/OR ADDITIONAL PARTS NEEDED

DATE	QUANTITY		NEW	USED
11-30	1	8' ½"	231.7	
11-30	1	8' ½"	239.7½	
11-30	1	8' ½"	247.8	
11-30	1	8' ½"	255.8½	
11-30	1	7' 9½"	263.6	
12-3	1	8' ½"	271.6½	
12-3	1	8' ½"	279.7	
12-4	1	8' ½"	287.7½	
12-4	1	8' ½"	295.8	
12-4	1	8' ½"	303.8½	
12-4	1	8' ½"	311.9	
12-8	1	8' ½"	319.9½	
12-10	1	8' ½"	327.10	
12-11	1	8' ½"	335.10½	
12-11	1	8' ½"	343.11	
12-12	1	8' ½"	351.11½	
12-12	1	8' ½"	360.	
12-12	1	7' 9"	367.9½	
12-13	1	8' ½"	375.10	
12-13	1	8' ½"	383.10½	

COACHELLA VALLEY PUMP & SUPPLY, INC.

SHOP WORK ORDER

JOB # Cable Tool Rig #1

JOB NAME Goldfields

DATE 11-22-84

DESCRIPTION OF WORK

Drill 16" hole to 800'

LIST REPLACEMENT AND/OR ADDITIONAL PARTS NEEDED

DATE	QUANTITY		NEW	USED
12-13	1	8' ½"	391-11	
12-13	1	8' ½"	399-11½	
12-13	1	8' ½"	408	
12-14	1	8' ½"	416½	
12-14	1	7' 9½"	423-10	
12-14	1	8' ½"	431-10½	
12-15	1	4'	435-10½	
12-15	1	4' ½"	439-11	
12-16	1	4'	443-11	
12-16	1	8' ½"	451-11½	
12-18	1	4'	455-11½	
12-18	1	8' ½"	464	
12-18	1	8' ½"	472-½	
12-18	1	8' ½"	480-1"	
12-18	1	8'	488-1"	
12-29	1	8' ½" Heavy sand and silt some gravel	496-1½	
12-29	1	8' ½" Sand and silt some gravel	504-2	
1-2	1	8' ½" sand and silt some gravel	512-2½	
1-2	1	8' ½" sand and silt some gravel	520-3	
1-3	1	8' ½" sand and silt some gravel	528-3"	

COACHELLA VALLEY PUMP & SUPPLY, INC.

SHOP WORK ORDER

JOB # Cable tool Rig #1

JOB NAME Goldfields

DATE 11-22-84

DESCRIPTION OF WORK

Drill 16" hold to 800'

LIST REPLACEMENT AND/OR ADDITIONAL PARTS NEEDED

DATE	QUANTITY		NEW	USED
1-3	1	8' ½" fine sand and silt	536-4	
1-3	1	first good perf. area 8' ½" sand from 538' thur 544'	544.4½"	
1-4	1	8' ½" fine to medium sand	552.5	
1-7	1	7' 9" sandy clay	560-2	
1-7	1	8' ½" clay	568-2½	
1-8	1	4' clay and sand stone	572-2½	
1-8	1	4' clay and silt	576-2½	
1-8	1	4' clay and silt	580-2½	
1-8	1	4' clay and silt	584-2½	
1-9	1	4' sand and gravel with some clay	588-2½	
1-9	1	4' sand and gravel with some clay	592-2½	
1-9	1	4' sand and gravel with some clay	596-2½	
1-9	1	4' sand and gravel with some clay	600-2½	
1-15	1	4' silty sand and clay (stinks)	604-2½	
1-15	1	4' silty sand and clay	608-2½	
1-15	1	4' brown silty sand with clay	612-2½	
1-16	1	4' brown silty sand with clay	616-2½	
1-17	1	4' brown silty sand with clay	620-2½	
1-17	1	4' brown silty sand with clay	624-2½	
1-17	1	4' brown silty sand with clay D.2-5	628-2½	

COACHELLA VALLEY PUMP & SUPPLY, INC.

SHOP WORK ORDER

JOB # Cable tool Rig #1

JOB NAME Goldfields

DATE 11-22-84

DESCRIPTION OF WORK

Drill 16" hole to 800'

LIST REPLACEMENT AND/OR ADDITIONAL PARTS NEEDED

DATE	QUANTITY		NEW	USED
1-17	1	4' brown silty sand with clay	632-2½	
1-17	1	4' " "	636-2½	
1-17	1	4' " "	640-2½	
1-18	1	4' brown silty sand and rocks with clay	644	
1-18	1	4' " "	648	
1-19	1	4' brown silty sand and clay	652	
1-19	1	4' " "	656	
1-20	1	4' brown silty sand and clay with rocks	660	
1-21	1	4' brown and red clay with rocks	664	
1-21	1	4' brown and red clay with rocks	668	
1-21	1	4' brown and red clay with rocks	672	
1-22	1	4' gravel and brown clay	676	
1-22	1	4' gravel with some clay	680	
1-22	1	4' gravel with some clay	684	
1-22	1	4' " "	688	
1-22	1	4' " "	692	
1-22	1	4' gravel (good gravel)	696	
1-23	1	4' gravel " "	700	
1-23	1	4' gravel to 702 then muck	704	
1-24	1	4' rocks and dirt	708	

COACHELLA VALLEY PUMP & SUPPLY, INC.

SHOP WORK ORDER

JOB # Cable Tool Rig #1

JOB NAME Goldfields

DATE 11-22-84

DESCRIPTION OF WORK

Drill 16" hole to 800'

LIST REPLACEMENT AND/OR ADDITIONAL PARTS NEEDED

DATE	QUANTITY		NEW	USED
1-24	4'	Rocks	712	
1-24	4'	" "	716	
1-24	4'	Rocks and dirt	720	
1-25	4'	Rocks and dirt some clay	724	
1-25	4'	Rocks and clay	728	
1-25	4'	" "	732	
1-25	4'	" "	736	
1-25	4'	Rocks, gravel and clay	740	
1-28	4'	Rocks and gravel	744	
1-28	4'	" "	748	
1-29	4'	Rocks and gravel with some clay	752	
1-29	4'	" "	756	
1-29	4'	" "	760	
1-29	4'	" "	764	
1-29	4'	" "	768	
1-30	4'	" "	772	
1-30	4'	" "	776	
1-30	4'	" "	780	
2-6	4'	" "	784	
2-7	4'	" "	788	

COACHELLA VALLEY PUMP & SUPPLY, INC.

SHOP WORK ORDER

JOB # Cable Tool Rig #1

JOB NAME Goldfields

DATE 11-22-84

DESCRIPTION OF WORK

Drill 16" hole to 800'

LIST REPLACEMENT AND/OR ADDITIONAL PARTS NEEDED

DATE	QUANTITY		NEW	USED
2-8	4'	Sand and gravel very little clay	792	
2-8	4'	sand and gravel some rock	796	
2-8	4'	sand and gravel	800	
2-8	4'	" "	804	
2-8	4'	" "	808	
2-9	4'	" "	812	
2-9	4'	" "	816	
2-9	4'	" "	820	
2-9	4'	" "	824	
2-9	4'	" "	828	
2-10	4'	" "	832	
2-12	4'	" "	836	
2-12	4'	" "	840	
2-12	4'	" "	844	
2-12	4'	" "	848	
2-12	4'	" "	852	
2-12	4'	" "	856	
2-12	4'	" "	860	
2-12	4'	" "	864	
2-12	4'	" "	868	

COACHELLA VALLEY PUMP & SUPPLY, INC.

SHOP WORK ORDER

JOB # Cable Tool Rig #1

JOB NAME Goldfields

DATE 11-22-84

DESCRIPTION OF WORK

Drill 16" hole to 800'

LIST REPLACEMENT AND/OR ADDITIONAL PARTS NEEDED

DATE	QUANTITY		NEW	USED
2-12	4'	Sand and gravel	872	
2-13	4'	" "	876	
2-13	4'	" "	880	
2-13	4'	" "	884	
2-13	4'	" "	888	
2-13	4'	" "	892	
2-13	4'	" "	896	
2-13	4'	" "	900	
2-14	4'	Sand and gravel with some clay	904	
2-14	4'	Sand and gravel with some clay	908	

APPENDIX D.3

GF-3A BORING LOG

QUADRUPLICATE
Use of comply with local requirements

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fi

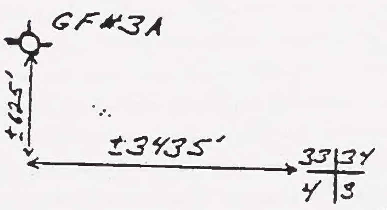
No. 19339

Notice of Intent No. 144153
Local Permit No. or Date

State Well No.
Other Well No.

(1) OWNER:
Name Goldfields Mining Corp.
Address HCR76, Glamis 100
City Brawley, Calif. Zip 92227

(2) LOCATION OF WELL (See instructions):
County Imperial Owner's Well Number GP-3
Well address if different from above
Township 13S Range R19E Section 33
Distance from cities, roads, railroads, fences, etc.



WELL LOCATION SKETCH

(3) TYPE OF WORK:
New Well ☒ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic ☐
Irrigation ☐
Industrial ☐
Test Well ☐
Stock ☐
Municipal ☐
Other ☒ Mining

(5) EQUIPMENT:
Rotary ☐ Reverse ☐
Cable ☒ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:
Yes ☒ No ☐ Size 5/16 x 4
Diameter of bore
Packed from 50 to 940 ft.

(7) CASING INSTALLED:
Steel ☐ Plastic ☐ Concrete ☐

From ft.	To ft.	Dia. in.	Gage or Wall
0	50	30"	1/4
0	940	16"	

(8) PERFORATIONS:
Type of perforation or size of screen Hydraulic Knife

From ft.	To ft.	Slot size
690	930	

10 cuts per round 3 rounds per ft. 30 cuts per ft.

(9) WELL SEAL:
Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 50 ft.
Were strata sealed against pollution? Yes ☐ No ☐ Interval ft.
Method of sealing Cement slurry

(10) WATER LEVELS:
Depth of first water, if known ft.
Standing level after well completion 469 ft.

(11) WELL TESTS:
Was well test made? Yes ☒ No ☐ If yes, by whom?
Type of test Pump ☒ Bailer ☐ Air lift ☐
Depth to water at start of test 474 ft. At end of test 560 ft
Discharge 2700 gal/min after 1½ hours Water temperature
Chemical analysis made? Yes ☐ No ☒ If yes, by whom?
Was electric log made? Yes ☐ No ☒ If yes, attach copy to this report

(12) WELL LOG:
Total depth 940 ft. Depth of completed well 940

from ft.	to	ft. Formation (Describe by color, character, size or material)
50	-	52 Sand and gravel
67	-	72 Sand, gravel and clay
72	-	82 Sand and gravel
82	-	163 Coarse sand and gravel
163	-	178 Med. hard rock with layers of cl
170	-	192 Coarse gravel and sand
192	-	198 Sand, gravel and clay
198	-	228 Clay with sand and gravel
228	-	245 Med. hard rock with clay
245	-	260 Sand and rock
260	-	336 Coarse gravel and sand
336	-	351 Coarse gravel and rock
351	-	384 Rock gravel, sand and some clay
384	-	405 Silty sand, little gravel with streaks of clay
405	-	432 Clay
432	-	487 Sand
487	-	491 Clay
491	-	501 Fine sand and gravel
501	-	510 Fine sand and clay
510	-	520 Sandstone
520	-	532 Silty sand
532	-	545 Sand, gravel and some clay
545	-	550 Sandy clay, little gravel
550	-	555 Sand
555	-	562 Sandstone and gravel
562	-	575 Sand, gravel and some clay
575	-	582 Cemented sand and gravel
582	-	595 Clay
595	-	610 Gravel
610	-	613 Sticky clay
613	-	620 Sand, gravel and some clay
620	-	645 Cemented sand and gravel, some cl
645	-	655 Cemented sand and gravel
655	-	697 Sand and gravel, with some clay
697	-	713 Gravel, rock and clay
	-	

- Continued on page two

Work started Sept. 19 85 Completed 3/30 19 86

WELL DRILLER'S STATEMENT:
This well was drilled under my jurisdiction and this report is true to the best of m knowledge and belief.

SIGNED
(Well Driller)

NAME Coachella Valley Pump & Supply, Inc.
(Person, firm, or corporation) (Typed or printed)
Address 83-801 Aven 48 / P. O. Drawer QQQ
City Indio, Calif. Zip 92201
License No. 161541 Date of this report 6/5/86

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED. USE NEXT CONSECUTIVELY NUMBERED FORM

UADRUPLICATE
Use of comply with local requirements

otice of Intent No. 144153
ocal Permit No. or Date

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fil

No. 193394

State Well No.
Other Well No.

CONFIDENTIAL
DO NOT FOR PUBLIC USE
WATER CODE SEC. 13752

(1) OWNER:

Name Goldfields Mining Corp.
Address HCR76, Clamis 100
City Brawley, Calif. Zip 92227

(2) LOCATION OF WELL (See instructions):

County Imperial Owner's Well Number CF03
Well address if different from above
Township 13S Range R19E Section 33
Distance from cities, roads, railroads, fences, etc.

WELL LOCATION SKETCH

(3) TYPE OF WORK:

New Well ☐ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:

Domestic ☐
Irrigation ☐
Industrial ☐
Test Well ☐
Stock ☐
Municipal ☐
Other ☐

(5) EQUIPMENT:

Rotary ☐ Reverse ☐
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:

Yes ☐ No ☐ Size
Diameter of bore
Packed from to ft.

(7) CASING INSTALLED:

Steel ☐ Plastic ☐ Concrete ☐

From ft.	To ft.	Dia. in.	Gage or Wall

(8) PERFORATIONS:

Type of perforation or size of screen

From ft.	To ft.	Slot size

(9) WELL SEAL:

Was surface sanitary seal provided? Yes ☐ No ☐ If yes, to depth ft.
Were strata sealed against pollution? Yes ☐ No ☐ Interval ft.
Method of sealing

(10) WATER LEVELS:

Depth of first water, if known ft.
Standing level after well completion ft.

(11) WELL TESTS:

Was well test made? Yes ☐ No ☐ If yes, by whom?
Type of test Pump ☐ Bailer ☐ Air lift ☐
Depth to water at start of test ft. At end of test ft
ischarge gal/min after hours Water temperature
Chemical analysis made? Yes ☐ No ☐ If yes, by whom?
Was electric log made? Yes ☐ No ☐ If yes, attach copy to this report

(12) WELL LOG:

Total depth 940 ft. Depth of completed well 940

from ft.	to ft.	Formation (Describe by color, character, size or material)
713	742	Gravel and clay
742	763	Gravel and sand
763	857	Sand, rock and gravel
857	940	Sand and gravel

Work started 19 Completed 19

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED (Well Driller)
NAME Coachella Valley Pump & Supply, Inc. (Person, firm, or corporation) (Typed or printed)
Address 83-801 Ave. 48 - P. O. Drawer QQQ
City Indio, Calif. Zip 92201
License No. 161561 Date of this report 6/5/86

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

APPENDIX D.4

MBH-1 BORING LOG

ORIGINAL
File with DWR

Notice of Intent No. 144154
Local Permit No. or Date

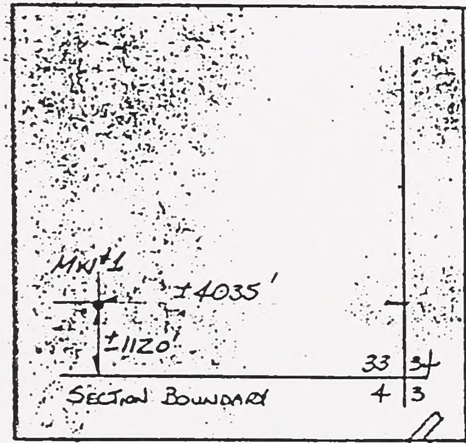
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fill in
No. 157626
State Well No.
Other Well No.

(1) OWNER: Name Goldfields Mining Corp.
Address P. O. Box 441
City Brawley, Ca. 92227 Zip

(2) LOCATION OF WELL (See instructions):
County Imperial Owner's Well Number one /
Well address if different from above
Township 13S Range 19E Section 33
Distance from cities, roads, railroads, fences, etc.



WELL LOCATION SKETCH

(3) TYPE OF WORK:
New Well ☒ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic ☐
Irrigation ☐
Industrial ☐
Test Well ☐
Stock ☐
Municipal ☐
Other monitor ☒

(5) EQUIPMENT:
Rotary ☒ Reverse ☐
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:
Yes ☒ No ☐ Size 4/16 mix
Diameter of bore 12¼
Packed from 300 to 600 ft.

(7) CASING INSTALLED:
Steel ☒ Plastic ☐ Concrete ☐

(8) PERFORATIONS: Mill cut
Type of perforation or size of screen

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
0	600	6 5/8	.250	510	590	90 mesh x 2½

(9) WELL SEAL: ~~Rotary mud slurry & cuttings~~
Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 300 ft.
Were strata sealed against pollution? Yes ☐ No ☐ Interval ft.
Method of sealing Rotary mud slurry & cuttings

(10) WATER LEVELS:
Depth of first water, if known ft.
Standing level after well completion ft.

(11) WELL TESTS:
Was well test made? Yes ☐ No ☐ If yes, by whom?
Type of test Pump ☐ Bailer ☐ Air lift ☐
Depth to water at start of test ft. At end of test ft
Discharge gal/min after hours Water temperature
Chemical analysis made? Yes ☐ No ☐ If yes, by whom?
Was electric log made? Yes ☒ No ☐ If yes, attach copy to this report

(12) WELL LOG: Total depth 600 ft. Depth of completed well 600 ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	30	Fine sand with small rock
30	185	Medium & corse sand with short streak of red clay and small pea gravel
185	240	Red clay with small rock
240	271	Medium and corse sand with small pea gravel
270	300	Pea gravel and small rocks with coarse to medium sand thin streaks of brown clay
300	420	gravel and small rocks with coarse, medium to fine sand
420	570	Medium and fine sand with small gravel with short streak of clay
570	600	Coarse sand with small rock

Work started 19 Completed 19

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED
(Well Driller)
NAME Coachella Valley Pump & Supply, Inc.
(Person, firm, or corporation) (Typed or printed)
Address P.O. Drawer QQQ
City Indio, Ca. 92202 Zip
License No. 161541 Date of this report 11/29/84

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

APPENDIX D.5

MBH-2 BORING LOG

ORIGINAL

File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fil

No. 157628

Notice of Intent No. 144154

Local Permit No. or Date

State Well No.

Other Well No.

(1) OWNER: Name Gold Fields Mining Corp.

Address P. O. Box 441

City Brawley, Ca. Zip 92227

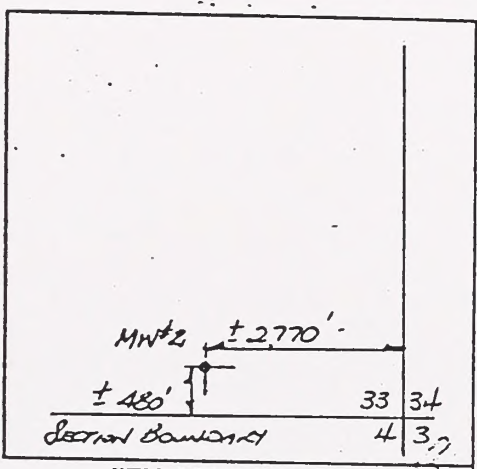
(2) LOCATION OF WELL (See instructions):

County Imperial Owner's Well Number 2

Well address if different from above

Township 13S Range 19E Section 33

Distance from cities, roads, railroads, fences, etc.



WELL LOCATION SKETCH

(3) TYPE OF WORK:

New Well ☒ Deepening ☐

Reconstruction ☐

Reconditioning ☐

Horizontal Well ☐

Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:

Domestic ☐

Irrigation ☐

Industrial ☐

Test Well ☐

Stock ☐

Municipal ☐

Other monitor ☒

(5) EQUIPMENT:

Rotary ☒ Reverse ☐

Cable ☐ Air ☐

Other ☐ Bucket ☐

(6) GRAVEL PACK:

Yes ☒ No ☐ Size 4-16 mix

Diameter of bore 12¼

Packed from 400 to 600 ft.

(7) CASING INSTALLED:

Steel ☒ Plastic ☐ Concrete ☐

(8) PERFORATIONS:

Type of perforation or size of screen

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
0	640	6 5/8	.250	510	630	90 mesh 2½

(9) WELL SEAL:

Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 400 ft.

Were strata sealed against pollution? Yes ☐ No ☐ Interval ft.

Method of sealing rotary mud slurry & cuttings

(10) WATER LEVELS:

Depth of first water, if known ft.

Standing level after well completion 470 ft.

(11) WELL TESTS:

Was well test made? Yes ☐ No ☐ If yes, by whom?

Type of test Pump ☐ Bailer ☐ Air lift ☐

Depth to water at start of test ft. At end of test ft

Discharge gal/min after hours Water temperature

Chemical analysis made? Yes ☐ No ☐ If yes, by whom?

Was electric log made? Yes ☒ No ☐ If yes, attach copy to this report

(12) WELL LOG: Total depth 640 ft. Depth of completed well 640

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	- 85	Fine, medium and coarse sand
	-	small rock and short streak of
	-	red clay, some larger boulders
85	- 115	Fine, medium to coarse sand an
	-	small rocks & gravel with a
	-	couple of short streaks clay
115	- 177	Fine, medium and coarse sand
	-	with streak of small rock
177	- 209	Fine, medium and coarse sand
	-	mixed with red clay
209	- 301	Fine, medium and coarse sand w
	-	small gravel mix
	-	Brown clay streaks
311	- 331	Coarse, medium to fine sand
	-	mixed with gravel and small roc
331	- 361	Corse medium to fine sand mixe
	-	with gravel and small rocks
	-	with short streaks brown clay
361	- 392	Red clay with streaks of small
	-	rocks and gravel with medium
	-	fine sand
392	- 422	Red clay with streaks of small
	-	rocks and gravel with medium
	-	fine sand
422	- 452	Red and blue clay with streaks
	-	of coarse to medium fine sand
452	- 482	Red and blue clay with streaks
	-	coarse to medium fine sand
482	- 513	Red clay with coarse medium
	-	to fine sand
513	- 544	Fine medium and coarse sand wit
	-	small gravel
544	- 575	In and out of red clay and medi
	-	coarse sand
575	- 640	In and out of red clay and medi
	-	coarse sand
	-	
	-	

Work started 19 Completed 19

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of m knowledge and belief.

SIGNED
(Well Driller)

NAME Coachella Valley Pump & Supply, In
(Person, firm, or corporation) (Typed or printed)

Address P.O. Drawer QQQ

City Indio, Ca. 92202 Zip

License No. 161541 Date of this report 11/29/84

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM D.5-1

APPENDIX D.6

MBH-3 BORING LOG

ORIGINAL
File with DWR

Notice of Intent No. 144154
Local Permit No. or Date

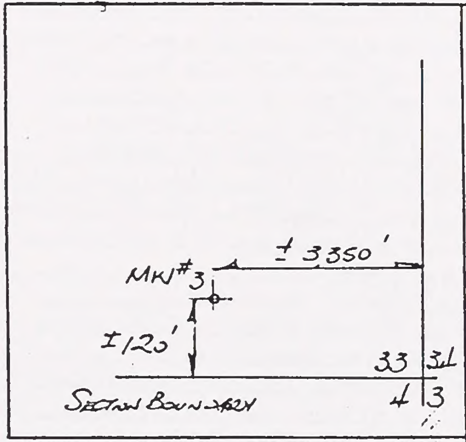
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fill in
No. 157627
State Well No.
Other Well No.

(1) OWNER: Name Gold Fields Mining Corp.
Address P. O. Box 441
City Brawley, Ca. Zip 92227

(2) LOCATION OF WELL (See instructions):
County Imperial Owner's Well Number 3
Well address if different from above
Township 13S Range 19E Section 33
Distance from cities, roads, railroads, fences, etc.



WELL LOCATION SKETCH

(3) TYPE OF WORK:
New Well ☒ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic ☐
Irrigation ☐
Industrial ☐
Test Well ☐
Stock ☐
Municipal ☐
Other monitor ☒

(5) EQUIPMENT:
Rotary ☒ Reverse ☐
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:
Yes ☒ No ☐ Size 4-16 mix
Diameter of bore 12¼
Packed from 400 to 680 ft.

(7) CASING INSTALLED:
Steel ☒ Plastic ☐ Concrete ☐

(8) PERFORATIONS:
Type of perforation or size of screen

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
0	680	65/8	.250	510	680	90 mesh
						2½

(9) WELL SEAL:
Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 400 ft.
Were strata sealed against pollution? Yes ☐ No ☐ Interval ft.
Method of sealing rotary mud slurry & cuttings

(10) WATER LEVELS:
Depth of first water, if known ft.
Standing level after well completion ft.

(11) WELL TESTS:
Was well test made? Yes ☐ No ☐ If yes, by whom?
Type of test Pump ☐ Bailer ☐ Air lift ☐
Depth to water at start of test ft. At end of test ft
Discharge gal/min after hours Water temperature
Chemical analysis made? Yes ☐ No ☐ If yes, by whom?
Was electric log made? Yes ☒ No ☐ If yes, attach copy to this report

(12) WELL LOG: Total depth 683 ft. Depth of completed well 683 ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	80	Medium and coarse sand with larger rock and small gravel
80	177	Medium and coarse sand with larger gravel and short streak of red clay.
177	331	Medium and coarse sand with small rock
331	637	Streak of sand in and out of clay. Medium and coarse sand
637	683	Medium and coarse sand, streak of small gravel

Work started 19 Completed 19

WELL DRILLER'S STATEMENT:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED
(Well Driller)
NAME Coachella Valley Pump & Supply, Inc
(Person, firm, or corporation) (Typed or printed)
Address P. O. Drawer QQQ
City Indio, Ca. 92202 Zip
License No. 161541 Date of this report 11/28/84

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

** TOTAL PAGE.002 **

ORIGINAL
File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fill in

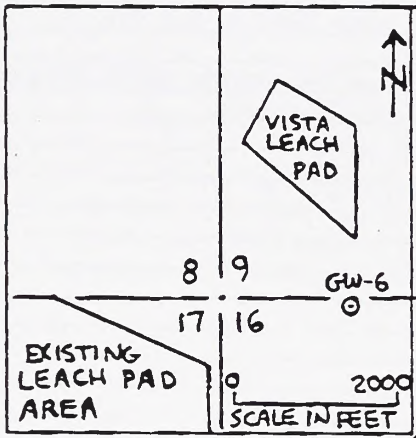
No. 322018

Notice of Intent No. ____
Local Permit No. or Date ____
State Well No. ____
Other Well No. ____

CONFIDENTIAL
DO NOT PUBLISH
WATER CODE SEC. 13752

(1) OWNER: Name GOLDFIELDSMINING CORP.
Address HIGHWAY 78
City HGR 76 GLAMIS 100/ BRAWLEY ZIP 92227

(2) LOCATION OF WELL (See instructions):
County IMPERIAL Owner's Well Number GW-6
Well address if different from above —
Township T13S Range R19E Section NW¼, NE¼, NW¼ 16
Distance from cities, roads, railroads, fences, etc. APPROX. 5 MILES EAST OF THE TOWN OF GLAMIS



WELL LOCATION SKETCH

(3) TYPE OF WORK:
New Well ☒ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic ☐
Irrigation ☐
Industrial ☐
Test Well ☐
Municipal ☐
Other ☒
(Describe) MONITOR

(5) EQUIPMENT:
Rotary ☐ Reverse ☒
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:
Yes ☒ No ☐ Size SAND
Diameter of bore 10"
Packed from -237.5 to -338

(7) CASING INSTALLED:
Steel ☐ Plastic ☒ Concrete ☐

(8) PERFORATIONS:
Type of perforation or size of screen

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
+2.5	-237.5	4	SCH.40	-237.5	-337.5	0.02"
-337.5	-338	4	SCH.40			

(9) WELL SEAL:
Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 3.2 ft.
Were strata sealed against pollution? Yes ☒ No ☐ Interval 0 - 228.8 ft.
Method of sealing CEMENT GROUT TO 221.5' BENT. TO 228.8

(10) WATER LEVELS:
Depth of first water, if known - 265.3', 1-9-90 ft.
Standing level after well completion - 250.2, 1-12-90 ft.

(11) WELL TESTS: 1-12-90
Was well test made? Yes ☒ No ☐ If yes, by whom? R. ALGER
Type of test Pump ☐ Bailer ☐ Air lift ☒
Depth to water at start of test -250.2 ft. At end of test 300.2 ft.
Discharge 1-2 gal/min after 5½ hours Water temperature —
Chemical analysis made? Yes ☐ No ☒ If yes, by whom? ____
Was electric log made? Yes ☐ No ☒ If yes, attach copy to this report

(12) WELL LOG: Total depth 400 ft. Completed depth 338 ft.
from ft. to ft. Formation (Describe by color, character, size or material)

0 - 20 ALLUVIUM: SANDY SILT, some to considerable fine angular to subangular gravel, trace clay, medium-fine sand, weakly lime cemented, nonplastic, Light brown. Gravels consist predominantly of brown, red brown & green metamorphic & volcanics.
20 - 400 CONGLOMERATE.: STRATIFIED SANDY GRAVELS, GRAVELLY SAND, SILTY GRAVELS & SANDY CLAY, fine-medium subangular gravels, medium to coarse sand, weakly to moderately lime cemented, nonplastic - medium plasticity, Light brown. Gravels consist predominantly of metamorphics & volcanics with granitics increasing with depth. Multicolored
20-30 Light brown clayey silt with fine subangular gravels.
30-80 Light brown sandy clay.
80-150 Light brown clayey silt with fine subangular gravels.
150-190 SILTY GRAVEL, fine-medium subangular gravel, Light brown some limonite 160-170'.
190-200 Considerable bright orange brittle claystone clasts.
200-240 Light brown silty gravels, fine gravel, predominantly metamorphic
240-270 sandy & silty gravels, fine-medium, predominantly granitics
270-280 Predom. black volcanic gravels
280-290 Silty gravels, fine, metamorphic
290-300 Light brown sandy clay.
300-340 Sandy & silty gravels, fine, granitics.
340-350 Light brown sandy clay.
350-370 Light brown silty gravel.
370-400 Sandy gravel, fine, granitics

Work started JAN. 8 1990 Completed JAN 12 1990

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

Signed Robert K Alger
(Well Driller)

NAME LAYNE WESTERN CO.
(Person, firm, or corporation) (Typed or printed)
Address 12030 E. RIGGS ROAD
City CHANDLER, ARIZONA ZIP 85227
License No. C-57452609 Date of this report JAN 12, 1990

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

SEP 22 '92 12:34 FROM GOLD FIELDS MESQUITE TO ENVI.SOL. PAGE.002

APPENDIX D.7

MCR-80 BORING LOG

LICATE
n.ply with
quirements

Intent No. 195548

mit No. or Date

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fill in

No. 137826

State Well No.

Other Well No.

(1) OWNER: Name Gold Fields Mining Corp.
Address 200 Union Blvd.
City Lakewood, CO Zip 80228

(2) LOCATION OF WELL (See instructions):
County Imperial Owner's Well Number MCR80
Well address if different from above Mesquite Mine
Township 13S Range 19E Section 15
Distance from cities, roads, railroads, fences, etc. Approx. 6 Miles NE E. of Glamis, CA.

WELL LOCATION SKETCH

(3) TYPE OF WORK:
New Well ☒ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic ☐
Irrigation ☐
Industrial ☐
Test Well ☒
Stock ☐
Municipal ☐
Other ☐

(5) EQUIPMENT:
Rotary ☒ Reverse ☐
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:
Yes ☒ No ☐ Size 3/8" x 4"
Diameter of bore 24"
Packed from 50' to 1002 ft.

(7) CASING INSTALLED:
Steel ☒ Plastic ☐ Concrete ☐

(8) PERFORATIONS: Machined
Type of perforation or size of screen

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
0	1002	12	.250	402	1002	2" x 1/8

(9) WELL SEAL:
Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 50 ft.
Were strata sealed against pollution? Yes ☐ No ☒ Interval ft.
Method of sealing Cement

(10) WATER LEVELS:
Depth of first water, if known ft.
Standing level after well completion 192.5 ft.

(11) WELL TESTS:
Was well test made? Yes ☒ No ☐ If yes, by whom? L.R. Hood
Type of test Pump ☒ Bailer ☐ Air lift ☐
Depth to water at start of test 192.5 ft. At end of test [illegible] ft
Discharge 50 gal/min after 39 hours Water temperature
Chemical analysis made? Yes ☐ No ☒ If yes, by whom?
Was electric log made? Yes ☒ No ☐ If yes, attach copy to this report

(12) WELL LOG: Total depth 1017 ft. Depth of completed well 1002 ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	30	Brown clay w/ rocks & gravel
30	79	Gravel w/ light brown clay
79	178	Gravel & brown clay
178	183	Fine brown sand, gravel all
		colors, quartz boulders
183	214	Fine brown sand, brown clay,
		gravel & few rocks
214	219	Fine brown sand, brown clay
219	231	Fine sand, few gravels, w/
231		brown clay
231	241	Brown clay, small gravels
241	271	Brown clay, fine brown sand &
		small gravels
271	314	Brown sand & gravel, tan clay
314	317	Gravel multicolored & sand
317	324	Tan clay, few rocks
324	353	Rocks & gravel, traces of sand
353	452	Light brown sand, fine gravel
		traces of black sand
452	488	Same as above w/ hard layers
		of black & brown sand stone
488	493	Sticky brown clay
493	514	Fine brown sand & gravel w/
		clay streaks
514	536	Sticky tan clay, few boulders
536	550	Fine light brown sand & gravel
		w/ streaks of tan clay
550	598	Same as above except less clay
598	602	Sticky tan clay
602	623	Same as above w/ gravel
623	626	Fine to medium gravel (no Clay)
626	635	Gravel w/ traces of tan clay
635	642	Tan clay w/ few gravels
642	677	Brown clay
677	741	Brown sticky clay & fine gravel
741	757	Same as above w/ more gravel
757	731	Tan clay & gravel
		- Continue next page-

Work started Jan. 18 19 83 Completed March 10 19 83

WELL DRILLER'S STATEMENT:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED
(Well Driller)

NAME L.R. Hood
(Person, firm, or corporation) (Typed or printed)
Address P.O. Box 780
City Yuma, AZ Zip 85364
License No. 265461 Date of this report 3/25/83

CONFIDENTIAL
NOT FOR PUBLIC USE
WATER CODE SEC. 13752

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

Imperial County

al. Duplicate and Triplicate with the
OF WATER RESOURCES
BOX 1279
AMENTO 5, CALIFORNIA

WATER WELL DRILLERS REPORT

(Sections 7076, 7077, 7078, Water Code)

SUPPLEMENTAL SHEET

Do Not Fill In

State Well No.

Other Well No.

Region

(5) Well log (continued):

Total depth of well 1002 ft.

Give details of formations penetrated, such as silt, peat, muck, sand, gravel, clay, shale, sandstone, hardpan, rock. Include size of gravel (diameter) and sand (fine, medium, coarse), color of material, structure (loose, packed, cemented, soft, hard, brittle).

Depth From Ground Surface				
781	ft. to	835	ft.	Tan clay, light brown sand & gravel
835	" "	840	"	Gray & blue clay traces of fine brown sand
840	" "	890	"	Blue clay
890	" "	943	"	Gray clay and gravel
943	" "	979	"	Gray clay & fine to medium coarse gravel
979	" "	937	"	Boulders & fine gravel (hard drilling)
987	" "	997	"	Rocks & boulders (hard) w/ thin streaks of brown sand
997	" "	1017	"	Gray sticky clay

If additional space is required continue on DWR Form No. 246—Supplement, and attach to respective report copies.

D W R Form No 246—Supplement

23973 3-50 20M QUIN SPO

APPENDIX E

GROUND WATER LEVEL ELEVATIONS

APPENDIX E

GROUND WATER LEVEL ELEVATIONS DATA EVALUATED FOR GROUND WATER CONTOUR MAP

Page 1 of 5

BORING OR WELL	LOCATION[1]		SURFACE ELEVATION	WATER LEVEL[2]					ELEVATION USED FOR CONTOURS
	RANGE, TOWNSHIP	SECTION		DURING DRILLING		ELEVATION AFTER STABILIZATION			
				DEPTH	ELEVATION	BY SHB	GFOC	ESI	
MR-66	R19E, T13S	17	640	260	380	436	435 TO 437		436
MR-69	R19E, T13S	13	770	272	498		488		488
MR-70	R19E, T13S	15	720	190	530		526 TO 528		528
MR-101	R19E, T13S	9	775	197	578				578
MR-102	R19E, T13S	9	779					564	564
MR-118	R19E, T13S	17	657	≈200	457		430		430
MR-120	R19E, T13S	17	670	160	510	490	470		470
MR-122	R19E, T13S	8	680	210	470				470
MR-144	R19E, T13S	9	755	350		535			535
MR-159	R19E, T13S	9	738	350	388			468	468
MR-160	R19E, T13S	9	725			450		449	450
MR-162	R19E, T13S	8	720	215	505				505
MR-163	R19E, T13S	8	719	220	499				499
MR-171	R19E, T13S	16	680	100	580	447		Dry to 215	447
MR-172	R19E, T13S	16	695	Dry	295-	445		Dry to 150	445
MR-173	R19E, T13S	17	640	265	375	433			433
MR-175	R19E, T13S	20	630	150	480		370		370
MR-176	R19E, T13S	9	755					537	537
MR-190	R19E, T13S	20	620	Dry	420-				420-
MR-191	R19E, T13S	29	595	Dry	395-			Dry to 193	402-

[1] See Figure 3.2 of main text for boring or well locations. Not all borings and/or wells shown in Figure 3.2 are listed in this table. See RDSI/ROWD Appendix R for logs for all borings and/or wells shown in Figure 3.2.

[2] A minus (-) after the water level indicates hole was dry to that level.

APPENDIX E

GROUND WATER LEVEL ELEVATIONS DATA EVALUATED FOR GROUND WATER CONTOUR MAP

(Continued)

Page 2 of 5

BORING OR WELL	LOCATION(1)		SURFACE ELEVATION	WATER LEVEL(2)					ELEVATION USED FOR CONTOURS
	RANGE, TOWNSHIP	SECTION		DURING DRILLING		ELEVATION AFTER STABILIZATION			
				DEPTH	ELEVATION	BY SHB	GFOC	ESI	
MR-192	R19E, T13S	10	767	160	607	530			530
MR-193	R19E, T13S	29	575	Dry	375-			Dry to 195	380-
MR-194	R19E, T13S	32	565	Dry	365-			Dry to 200	365-
MR-197	R19E, T13S	10	840	215-240	600-625				625
MR-198	R19E, T13S	10	750			565			565
MR-200	R19E, T13S	10	760	Dry	560-	580			580
MR-201	R19E, T13S	15	710	Dry		530			530
MR-206	R19E, T13S	15	710	150	560				560
MR-209	R19E, T13S	20	605	Dry	205-		290		290
MR-211	R19E, T13S	20	595	120	475			Dry to 215	Not Used - Dry
MR-212	R19E, T13S	20	570	Dry	370-			Dry to 200	Not Used - Dry
MR-213	R19E, T13S	29	560	160	400			361	363
MR-214	R19E, T13S	30	540	60	480	Dry			Not Used - Dry
MR-215	R19E, T13S	30	520	Dry	283-				Not Used - Dry
MR-217	R19E, T13S	29	550	160	390			Dry to 200	350
MR-221	R19E, T13S	30	515	Dry	315-			Dry to 200	315
MR-256	R19E, T13S	18	635	340	295				Not Used - Low
MR-257	R19E, T13S	8	680	170	510				510
MR-258	R19E, T13S	7	660	140	520				520

(1) See Figure 3.2 of main text for boring or well locations. Not all borings and/or wells shown in Figure 3.2 are listed in this table. See RDSI/ROWD Appendix R for logs for all borings and/or wells shown in Figure 3.2.

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APPENDIX E

GROUND WATER LEVEL ELEVATIONS DATA EVALUATED FOR GROUND WATER CONTOUR MAP

(Continued)

Page 3 of 5

BORING OR WELL	LOCATION(1)		SURFACE ELEVATION	WATER LEVEL(2)					ELEVATION USED FOR CONTOURS
	RANGE, TOWNSHIP	SECTION		DURING DRILLING		ELEVATION AFTER STABILIZATION			
				DEPTH	ELEVATION	BY SHB	GFOC	ESI	
MR-265	R19E, T13S	18	585	Dry	185-				Not Used - Dry
MR-266	R19E, T13S	17	625	Dry	225-				Not Used - Dry
MR-267	R19E, T13S	19	580	Dry	180-			242	242
MR-268	R19E, T13S	19	562	Dry	162-				Not Used - Dry
MR-269	R19E, T13S	19	555	Dry	155-				Not Used - Dry
MR-270	R19E, T13S	19	530	Dry	130-				Not Used - Dry
MR-273	R18E, T13S	12	620	100	520				520
MR-274	R18E, T13S	1	660	140	520				520
MR-277	R19E, T13S	11	785	182	603				603
MR-278	R18E, T13S	1	670	130	540				540
MR-290	R19E, T13S	3	832	240	592				592
MR-304	R19E, T13S	9	760					537	537
MR-307	R19E, T13S	4	815					576	576
MR-377	R18E, T13S	15	465	115	350				350
MR-385	R20E, T13S	18	830	80	750				750
MR-418	R19E, T13S	3	818						562
MR-454	R19E, T13S	9	764						546
MR-478	R19E, T13S	9	769						542

(1) See Figure 3.2 of main text for boring or well locations. Not all borings and/or wells shown in Figure 3.2 are listed in this table. See RDSI/ROWD Appendix R for logs for all borings and/or wells shown in Figure 3.2.

(2) A minus (-) after the water level indicates hole was dry to that level.

APPENDIX E

GROUND WATER LEVEL ELEVATIONS DATA EVALUATED FOR GROUND WATER CONTOUR MAP
(Continued)

Page 4 of 5

BORING OR WELL	LOCATION(1)		SURFACE ELEVATION	WATER LEVEL(2)					ELEVATION USED FOR CONTOURS
				DURING DRILLING		ELEVATION AFTER STABILIZATION			
	RANGE, TOWNSHIP	SECTION		DEPTH	ELEVATION	BY SHB	GFOC	ESI	
MR-485	R19E, T13S	13	798	230	568				568
MR-493	R19E, T13S	9	753					539	539
MR-501	R19E, T13S	10	786					553	53
MR-525	R19E, T13S	9	762					562	562
MR-560	R19E, T13S	9	765					543	543
MR-585	R19E, T13S	9	760					545-	545-
MR-584	R19E, T13S	9	763					579-	579-
MR-633	R19E, T13S	4	769					546	546
MR-670	R19E, T13S	3	839					563	563
GW-1	R19E, T13S	18	590					280	280
GW-2	R19E, T13S	20	630					362	362
GW-3	R19E, T13S	17	650					437	437
GW-4	R19E, T13S	18	725					504	504
SHB-20B	R19E, T13S	17	615					305	305
WT-2	R19E, T13S	5					550		550
MCR-80	R19E, T13S	15	720	192	528	528		523	523
SINGER	R19E, T13S	4						575	575
BOARDMAN	R18E, T13S	34	404				95		95
GLAMIS	R18E, T13S	36	335					100	100
GF-1	R19E, T13S	33	553				79	79	79

(1) See Figure 3.2 of main text for boring or well locations. Not all borings and/or wells shown in Figure 3.2 are listed in this table. See RDSI/ROWD Appendix R for logs for all borings and/or wells shown in Figure 3.2.

(2) A minus (-) after the water level indicates hole was dry to that level.

APPENDIX E

GROUND WATER LEVEL ELEVATIONS DATA EVALUATED FOR GROUND WATER CONTOUR MAP

(Continued)

BORING OR WELL	LOCATION(1)		SURFACE ELEVATION	WATER LEVEL(2)					ELEVATION USED FOR CONTOURS
	RANGE, TOWNSHIP	SECTION		DURING DRILLING		ELEVATION AFTER STABILIZATION			
				DEPTH	ELEVATION	BY SHB	GFOC	ESI	
GF-2	R19E, T13S	33	540				78	78	78
GF-3A	R19E, T13S	33	546	469	77				77
MBH-1	R19E, T13S	33	545				78	81	78
MBH-2	R19E, T13S	33	545				75	80	80
MBH-3	R19E, T13S	33	536				78	79	78

91-296 (11/7/93/jtw)

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(1) See Figure 3.2 of main text for boring or well locations. Not all borings and/or wells shown in Figure 3.2 are listed in this table. See RDSI/ROWD Appendix R for logs for all borings and/or wells shown in Figure 3.2.

(2) A minus (-) after the water level indicates hole was dry to that level.

APPENDIX F

COREHOLE, MINE GROUNDWATER MONITORING WELL AND LANDFILL GROUNDWATER MONITORING WELL LOGS

F.1 - BORING LOG OF ESI-1
F.2 - LITHOLOGIC LOGS OF GW-1 THROUGH GW-5
F.3 - BORING LOG OF GW-6
F.4 - BORING LOG OF ESI-2
F.5 - LITHOLOGIC LOG AND WELL COMPLETION DETAILS OF LGW-1
F.6 - LITHOLOGIC LOG AND WELL COMPLETION DETAILS OF LGW-2

APPENDIX F.1

BORING LOG OF ESI-1

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E; 99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 1 OF 11
CORE SIZE: HQ-2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
1		37.5	ALLUVIUM	Loose	Med. reddish gray angular to subanguler gravel, matrix mostly washed out, sandy clay.						Started drilling at 2:10 pm 5-5-85 1st run - 0.3 ft./min.
2	5	70		Mod. Dense	Med. brown, slightly reddish clayey sand with 15% scattered gravel, angular to subangular.						2nd run - 0.1 ft./min.
3		94			Red-reddish brown gravelly sand with clayey matrix, gravel 30% >2 1/2", average 1" in. 0, subenguler, poorly cemented.						3rd run - 11.4 ft./hr. 4th run = 10.9 ft./hr.
4	10	100	BEAR CANYON CONGLOMERATE	Soft to Med. Hard	Med. reddish brown clayey conglomerate, subangular to subrounded clasts, 2.5" 0, average 1" 0, caliche impregnation in pockets, medium cementation						Stopped @ 5 pm (13 ft.)
5	15	100			Med. reddish brown gravelly SS, coarse sand to pea gravel, subangular to subrounded. (volcanics, intrusive, metam.) matrix clayey sand, poorly cemented	Mod.					5/6/85 started drilling @ 8:50
6	20	93			Interbedded sandy cg. and gravelly Cg 4-6" thick, SS = 1-3" thick beds. Clasts are coated with thin (<1/16") caliche layer. Cg. are cemented with caliche.						6th run = 12.5 ft./hr. 7th run - 12 ft./hr.
7											

NOTES: Drilling Contractor - Longyear, Phoenix, Arizona.
Driller - Norman Leland
Drilling Mud - Dextrid (10 qts.) Quick Gel (50 lbs.) E-Z Mud (5 qts.)

0-24 ft - 100% Water Circulation
SS = Sandstone
cg = Conglomerate

ENVIRONMENTAL SOLUTIONS, INC.

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E;99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 2 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING			REMARKS
								GRAPHIC	JTS/( )	DIP	
7	25	94		Med. Hard	No open fractures or joints						
				Soft to Med. Hard	Med. reddish to gray brown interbedded gravelly SS and sandy conglomerate, subangular clasts 1/4" to 4" 0 Average 1/2". Matrix is clayey sand, well cemented with caliche, poorly bedded with graded beddings. Subhorizontal beddings - hard, no fractures or joints	Mod.					8th run = 10 ft./hr.
8	30	96									9th run = 14 ft./hr.
9	35	95		Soft to Med. Hard	Med. red brown interbedded gravelly, SS and sandy conglomerate. SS is coarse with pea gravel, poorly cemented, cg has subangular to subrounded clasts 1/4" - 2" 0 well cemented.	Mod.					10th run = 16 ft./hr.
10	40	90		Soft	39 1/2 coarse gravelly sandstone. Matrix is clayey, pea gravel. close to 50% Poorly bedded to massive						11th run = 16 ft./hr.
11	45	90			Interbedded med. red brown clayey cg and gravelly sandstone. The cg is cemented by caliche, hard & indurated						

NOTES: 100% Water Circulation

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E;99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 3 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING			REMARKS
								GRAPHIC	JTS/( )	DIP	
11		90		Soft to Med. Hard	Gravel subrounded to rounded, poor to well cemented. Interbedded med. red brown clayey to gravelly SS and clayey to sandy cg; Conglom. well cemented and SS med. cemented. Beds ranging from 2" to 6" thick				BREAKS ALONG GRAIN BOUNDARY		
12	50	90				Mod.					12th run = 17 ft./hr.
13	55	94		Soft to Med. Hard	Interbedded med. grey coarse SS, poorly cemented & sandy (clayey) cg. (15%) well cemented with caliche, clasts subrounded, poorly bedded						13th run = 13 ft./hr.
14	60	100		Soft	Med. red brown coarse grained gravelly SS, small amount clayey matrix, poorly consolidated, poorly cemented, friable. Gravel up to 1/2" 0 - angular to subrounded, gradational to coarse sand Few 3-6" thick sandy conglomerates	Mod.					14th run = 20 ft./hr.
15	65	90									15th run = 20 ft./hr.
16											16th run = 25 ft./hr.

NOTES: ~100% circulation. Water dropped ~ 1 ft. in a 200 gal. tank, drilling between 25-77 ft.

ENVIRONMENTAL SOLUTIONS, INC.

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E;99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 4 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
16	70	98		Soft		Slgt to Mod.					
17	75	±90		Med. H Soft Med H.	Slightly reddish gray cl-y cg. clasts subrounded to subangular 1 1/4 -3" 0 gravelly coarse SS. very weakly cemented, gravel ~ 10-15% aug. clasts Clayey conglomerate.						17th run = 15.6 ft/hr Difficult to estimate recovery as it comes apart. Stopped drilling @ 4:30 pm @ 77 ft
18	80	94		Soft Med. H Soft Med. H Soft Med. H	Interbedded slightly red gray coarse clayey SS and sandy cg. with clayey matrix - clasts subangular Sand clasts angular to subaugular, little fines. Occas. 2-3" layers of fine clayey sand @ 80.5 feet color changes from slight reddish gray to reddish gray. Caliche impreg. to 81.0'	Slgt to Mod.					5-7-85 Started drilling @ 7:50 am 18th run = 14.7 ft./hr.
19	85	97		Soft Med. Hard	@ 84.0' reddish brown clayey conglomerate, clasts subangular to subrounded 1/8"-1" 84-84.5' high caliche, below 84.5 present in pockets and coating clasts						19th run = 26.3 ft./hr. 20-30° Bedding
20	90	100			Interbedded clayey cg and gravelly SS, reddish brown - layers 3"-6" thick - clasts subrounded - caliche irregular in layers	Mod.					20th run = 16 ft./hr.

NOTES: 100% Water Circulation
Slgt = Slight

ENVIRONMENTAL SOLUTIONS, INC.

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E;99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 5 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING			REMARKS
								GRAPHIC	JTS/( )	DIP	
21	95	100		Med. Hard	Light gray tan sandy cg. clasts subrounded to subangular 2 1/2". Matrix med. silty sand, well cemented with calcareous material.	Slgt		NO JOINTS OR	FRACTURE BREAKS	ALONG SUBHORIZONTAL SURFACES 0-15°	21st run = 15.6 ft./hr.
				Soft	Interbedded light gray tan gravelly sand, poorly cemented						
22	100	100		Med. Hard	Light gray tan sandy cg. clasts subrounded up to 4 1/2" 0 matrix silty sand, well cemented.						22nd run = 15 ft./hr. 12° Bedding
23	105	100		Soft	Med. tan brown fine micaceous silty SS, poorly cemented						
				Med. Hard	Light gray tan sandy cg. massive, well cemented						
24	110	100		Soft	Med. tan brown fine micaceous silty SS, poorly cemented, less than 3% scattered gravel up to 4" in diam - massive						24th run = 20 ft./hr.
				Soft to Med. Hard	Med. tan gray to subangular sandy cg., clasts subrounded up to 3 1/2" matrix fine silty sand, poorly cemented						25th run = 16 ft./hr.
25											

NOTES: 100% Water Circulation

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E;99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 6 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
25	115	100		Soft to Med. Hard		Slgt					
26	120	98			Med. grey tan gravelly SS with interbedding sandy cg. layers 2-4" thick. SS is med. grained well sorted silty matrix poorly cemented. Cg. 1/4-2" 0 clasts, surrounded silty sand matrix, med. cementation.						
27	125	100			Med. tan brown sandy cg. clasts subangular to subrounded 1/4-2" 0 matrix fine silty sand mod. cemented, massive.	Slgt					
28	130	97		Soft	Med. brown tan fine silty sandstone. massive, poorly cemented.						28th run = 16 ft./hr.
				Soft to Med. Hard	Med. tan brown gravelly sand scattered gravel 20-40% subanguler, subrounded, matrix silty sandstone.						
29	135	100			Med. tan brown sandy cg. mod. well cemented, clasts up to 3" diameter, subrounded, layers 2-3" thick of SS						29th run = 16 ft./hr.
				Soft	Med. tan brown sandy siltstone well bedded, poorly cemented.	Slgt					

NOTES: 100% Water Circulation

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E; 99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 7 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING			REMARKS
								GRAPHIC	JTS/( )	DIP	
30	140	100		Soft to Med. Hard	Med. tan brown graded bedded sequences 8-9" thick, from sandy cong. to fine SS poorly bedded, breaks along bedding planes. Moderately well cemented.	Slgt				20°	Breaks along shear surfaces with polished clayey coating dipping 10-20° @ 135.5, same polished surface dippings 75°
31	145	100				Slgt			Bedding 10°		31st run = 18 ft./hr.
32	150	100		Soft to Med. Hard	Med. tan brown interbedded silty SS with layers of sandy cg. 3-6" thick. SS ranges from gravelly to very fine. Cg has clasts up to 2" in diameter. Poorly bedded breaks along bedding planes. Moderate to poorly cemented.	Slgt			Bedding 20°	70°	32nd run = 17.8 ft./hr. Joint parting surface tight, no infilling
33	155	100		Soft to Mod. Hard	Medium to light silty to gravelly SS, layers 2-3" thick of gravel. Poorly cemented, poorly bedded.						Stopped drilling @ 4:30 pm @ 157 ft.
34											5-8-85 - Started drilling @ 7:45 am 34th run = 13 ft./hr.

NOTES: 77 to 157 ft. = 100% Water Circulation

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E; 99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 8 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING			REMARKS
								GRAPHIC	JTS/( )	DIP	
34	160	100		Soft to Med. Hard	Med. tan brown interbedded sandy cg and silty sand. Cg clasts subrounded up to 1.5", poorly cemented, silty SS, fine grained, angular clasts, poorly cemented gravel layers 4-6" thick, SS layers = 1-6". Poorly bedded.	Slgt					Beddings 25°
35	165	100									
36	170	100			Med. tan brown interbedded silty, fine to med. grained SS and fine sandy cg. Cg 4-6" thick, SS 1-6", moderately cemented, poorly bedded.						
37	175	100		Soft to Med. Hard	@ 172.0 red brown tan fine silty sand, finely laminated with dark minerals, cross bedded, poorly cemented.	Slgt					Beddings 20° 38th run = 13 ft./hr.
38	180	100			@ 177.5 red tan brown fine to very fine silty SS, finely laminated (heavy minerals) cross bedded, poorly to moderately cemented.	Slgt to Very Slgt					

NOTES:

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E;99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 9 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
39	185	100		Soft to mod hard	@184.5 layer of gravelly sand, clasts up to 1" O subrounded, poorly cemented. 185.0 Finely laminated, silty SS. scattered gravel. @186.0 Faultlet offsetting unit ~ 6".	Slgt to v. Slgt					Bedding 30° 186' Faultlet dipping 50°
40	190	100		Mod hard	187.3 Med. gray, brown (light gray when dry) fine silty SS, laminated very homogenous grain size, mod. well cemented - breaks along bedding places. gravelly ss 3" thick .Clasts 1/4 - 1" O.						188-190 hit small amount of water. 40th run = 13 ft/hr
41	195	100		Mod. hard	192.8 Med. gray brown gravelly SS - gravel ~40% varigated color. 1/8'-1" O - Mod. cemented poorly bedded to massive.						
42	200	100		Mod. hard	Med. brown med. to fine silty sand in thicknesses of 2-4" between 1/4" layers of sandy silt & clay - breaks along clayey layers which are polished, well bedded, mod cementation.	Slgt to V. Slgt					Bedding 20°
43		100									

NOTES:

ENVIRONMENTAL SOLUTIONS, INC.

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E;99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 10 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
43	205	100			Micro fracture w/displacement of <1/2" bounded by continuous planes.						
				Med. hard	Mudstone & fine SS soft sediment deformation medium cementation.	very slgt					Bedding = 25°
44	210	100			Med. brown med. silty SS well bedded, mud-cement						
					Med. gray, med. silty SS, massive to well bedded (heavy minerals layering) Well cemented occassional scattered gravel.	very slgt					46th run = 20 ft/hr
45	215	100									
				Med. hard	Med. gray sandy cg, clasts subrounded up to 4" O average 1/4-1" - Matrix silty sand, med. cementation massive.						Stopped drilling @ 16:00, @ 200 Ft.
46		100									
	220										5-9-85 Started drillings @ 9:00, @ 200 Ft. Bedding 30°
47		100									
	225			Soft to Med. hard	Med. brown silty SS w/ 5% scattered gravel, med. to fine grained.						

NOTES:

ENVIRONMENTAL SOLUTIONS, INC.

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 85-030B	PROJECT NAME: Gold Fields - Mesquite	
BORING NUMBER: ESI-1	ELEVATION: 638.5 (approx.)	DATE STARTED: 5-5-85
COORDINATES: 211,619E;99,745N		DATE COMPLETED: 5-9-85
DRILLING METHODS: Rotary		PAGE 11 OF 11
CORE SIZE: HQ 2 1/2"	ENG./GEO. L. Lustig	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	% RQD	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
48	230	97		Soft to med. hard	Med. brown coarse gravelly SS, matrix silty sand, gradational to layers 3" thick of sandy gravel - gravel subrounded up to 3" O average 1/4" poorly bedded.						48th run = 20 ft/hr
49	235	100		Med. hard	Interbedded sandy cg (10%) and gravelly SS (90%) - cg 1-3" thick from 234.8 to 235.5 bedding determined by heavy minerals layering. Mod.-well cemented.						Bedding = 15°
50	240	97		Med. hard to hard	Med. brown, med. grained, clean SS, ang to subang grains, mod. cemented, interbedded gravelly SS 1" thick, well bedded laminated some soft sediment deformation 240.5-241.0 fine SS to silt/clayey layers <1/16".	very slgt					Interbedded Bedding = 30°
51	245			Med. hard to hard	Med. gray well sorted SS, med. grained, well cemented, well bedded (bedding by heavy minerals layering 1/8" to 1").						
52	250				Med. gray fine silty SS, well sorted layers of med SS. 247.0 Med. gray gravelly SS 15% gravel, clasts subrounded up to 1/2" - average 1/4" - grades @ 249.5 to sandy cg - well cemented.						52nd run = 12 ft/hr

NOTES:

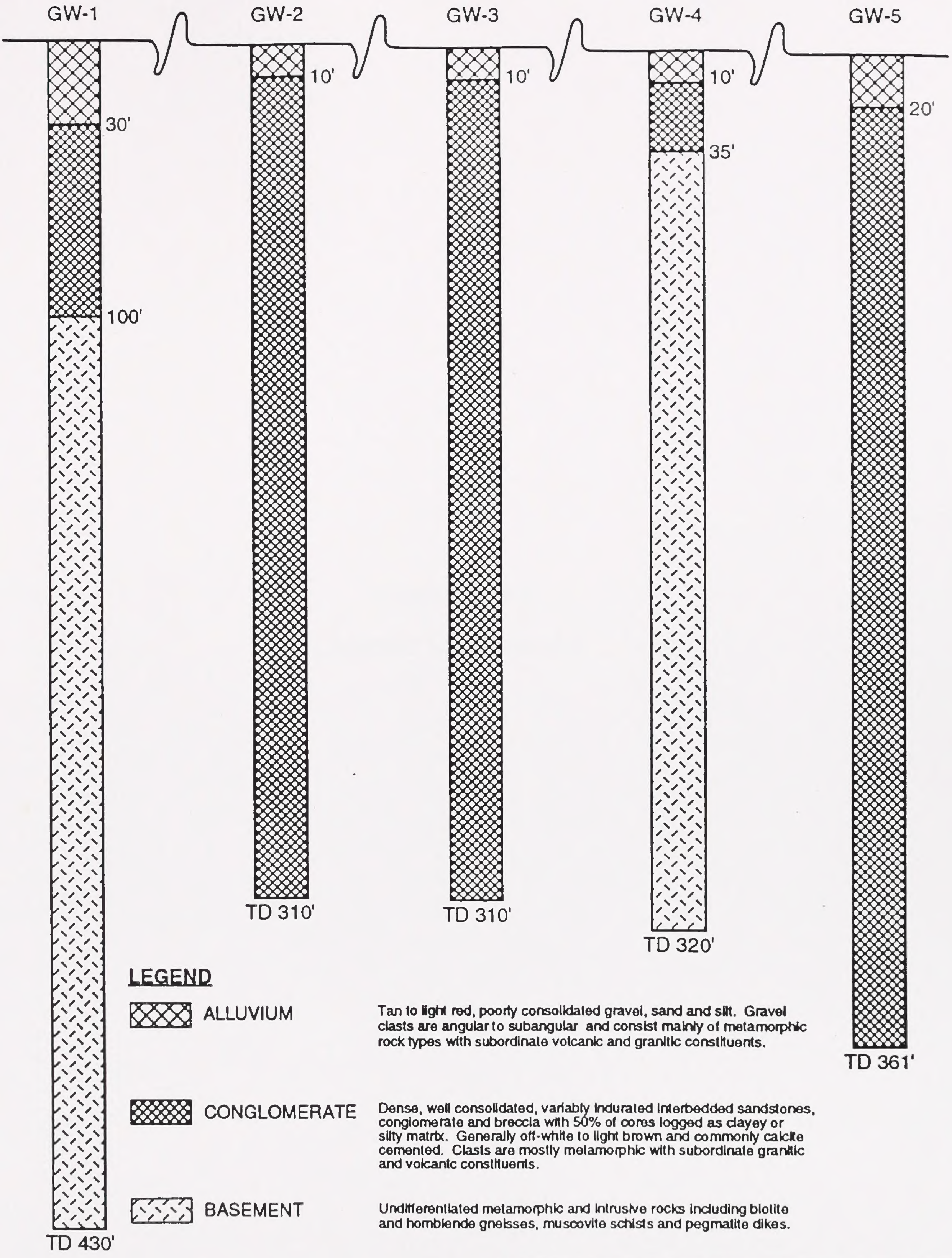
TD = 250.0 Feet
Finished drilling 5-9-85 @ 1:00 p.m.
100% water circulation from 157-250 FT.

ENVIRONMENTAL SOLUTIONS, INC.

APPENDIX F.2

LITHOLOGIC LOGS OF GW-1 THROUGH GW-5

91-296HARF-01 REV.08/28/93



LEGEND

ALLUVIUM	Tan to light red, poorly consolidated gravel, sand and silt. Gravel clasts are angular to subangular and consist mainly of metamorphic rock types with subordinate volcanic and granitic constituents.
CONGLOMERATE	Dense, well consolidated, variably indurated interbedded sandstones, conglomerate and breccia with 50% of cores logged as clayey or silty matrix. Generally off-white to light brown and commonly calcite cemented. Clasts are mostly metamorphic with subordinate granitic and volcanic constituents.
BASEMENT	Undifferentiated metamorphic and intrusive rocks including biotite and hornblende gneisses, muscovite schists and pegmatite dikes.

FIGURE F.2-1

LITHOLOGIC LOGS OF GW-1 THROUGH GW-5

MESQUITE REGIONAL LANDFILL

APPENDIX F.3

BORING LOG OF GW-6

RIGINAL
le with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fill in

No. 322018

Notice of Intent No. ______

Local Permit No. or Date ______

State Well No. ______

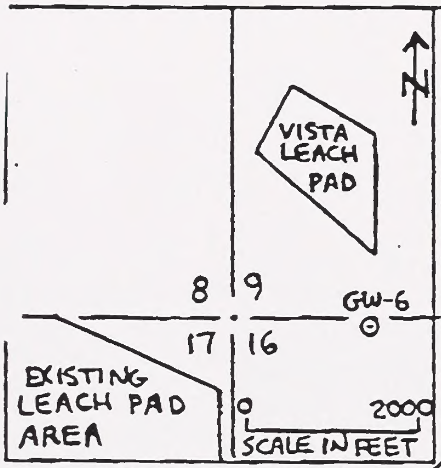
Other Well No. ______

(1) OWNER:

Name GOLDFIELDSMINING CORP.
Address HIGHWAY 78
City HGR 76 GLAMIS 100/ BRAWLEY ZIP 92227

(2) LOCATION OF WELL (See instructions):

County IMPERIAL Owner's Well Number GW-6
Well address if different from above —
Township T13S Range R19E Section NW¼, NE¼, NW¼ 16
Distance from cities, roads, railroads, fences etc. APPROX. 5 MILES EAST OF THE TOWN OF GLAMIS



WELL LOCATION SKETCH

(3) TYPE OF WORK:

New Well ☒ Deepening ☐
Reconstruction ☐
Reconditioning ☐
Horizontal Well ☐
Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:

Domestic ☐
Irrigation ☐
Industrial ☐
Test Well ☐
Municipal ☐
Other ☒
(Describe) MONITOR

(5) EQUIPMENT:

Rotary ☐ Reverse ☒
Cable ☐ Air ☐
Other ☐ Bucket ☐

(6) GRAVEL PACK:

Yes ☒ No ☐ Size SAND
Diameter of bore 10"
Packed from -237.5 to -338

(7) CASING INSTALLED:

Steel ☐ Plastic ☒ Concrete ☐

(8) PERFORATIONS:

Type of perforation or size of screen

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
+2.5	-237.5	4	SCH.40	-237.5	-337.5	0.02"
-337.5	-338	4	SCH.40			

(9) WELL SEAL:

Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 3.2 ft.
Were strata sealed against pollution? Yes ☒ No ☐ Interval 0 - 228.8 ft.
Method of sealing CEMENT GROUT TO 221.5', BENT. TO 228.8

(10) WATER LEVELS:

Depth of first water, if known - 265.3', 1-9-90 ft.
Standing level after well completion - 250.2, 1-12-90 ft.

(11) WELL TESTS: 1-12-90

Was well test made? Yes ☒ No ☐ If yes, by whom? R. ALGER
Type of test Pump ☐ Bailer ☐ Air lift ☒
Depth to water at start of test -250.2 ft. At end of test 300.2 ft.
Discharge 1-2 gal/min after 5½ hours Water temperature —
Chemical analyses made? Yes ☐ No ☒ If yes, by whom? ______
Was electric log made Yes ☐ No ☒ If yes, attach copy to this report

(12) WELL LOG:

Total depth 400 ft. Completed depth 338 ft.

from ft. to ft. Formation (Describe by color, character, size or material)

0 - 20 ALLUVIUM: SANDY SILT, some to considerable fine angular to subangular gravel, trace clay, medium-fine sand, weakly lime cemented, nonplastic, Light brown. Gravels consist predominantly of brown, red brown & green metamorphic & volcanics.

20 - 400 CONGLOMERATE: STRATIFIED SANDY GRAVELS, GRAVELLY SAND, SILTY GRAVELS & SANDY CLAY, fine-medium subangular gravels, medium to coarse sand, weakly to moderately lime cemented nonplastic - medium plasticity, Light brown. Gravels consist predominantly of metamorphics & volcanics with granitics increasing with depth, Multicolored

20-70 Light brown clayey silt with fine subangular gravels.

70-80 Light brown sandy clay.

80-150 Light brown clayey silt with fine subangular gravels.

150-190 SILTY GRAVEL, fine-medium subangular gravel, Light brown some limonite 160-170'.

190-200 Considerable bright orange brittle claystone clasts.

200-240 Light brown silty gravels, fine gravel, predominantly metamorphic

240-270 Sandy & silty gravels, fine-medium, predominantly granitics

270-280 Predom. black volcanic gravels

280-290 Silty gravels, fine, metamorph.

290-300 Light brown sandy clay.

300-340 Sandy & silty gravels, fine, granitics.

340-350 Light brown sandy clay.

350-370 Light brown silty gravel.

370-400 Sandy gravel, fine, granitics

Work started JAN. 8 1990 Completed JAN 12 1990

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

Signed Robert K Alger
(Well Driller)

NAME LAYNE WESTERN CO.
(Person, firm, or corporation) (Typed or printed)
Address 12030 E. RIGGS ROAD
City CHANDLER, ARIZONA ZIP 85227
License No. C-57452609 Date of this report JAN 12, 1990

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

CONFIDENTIAL
NOT FOR PUBLIC
WATER CODE SEC

APPENDIX F.4

LITHOLOGIC LOG OF ESI-2

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 1 OF 9
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
1		0		Younger Alluvium: Grey, loose sands and gravels, topped with desert pavement. -Intermediate Alluvium: Reddish brown silty sands and gravels, layers of very good caliche development, moderately cemented otherwise, clasts of igneous and metamorphic origin, ranging in size from cobbles to silt, grains are subangular, very little moisture.	Slt. W					Start at 1020.
	5									
2		100								
	10									
3		100		-Bear Canyon Conglomerate: Brown to reddish brown, sand and gravel conglomerate, trace silts, angular to subangular clasts, poorly consolidated, massive structure, not cemented.	M					
	15									
4		93		-17' formation more consolidated, still not well cemented.						
	20									
5		100		-20' range of clasts from 2" diameter gravels to silts and clays.	W					
	25									
6		100		-texture is coarser, less fines.	W M					
	30									
7		100								
	35									
8		100		↕ -zone of less consolidation and/or cementation. -clasts ranging to 3 - 4" diameter.						
	40									

NOTES:
Slt = Slightly Weathered
M = Moderately Weathered
W = Weathered

Mud is 50 viscosity.
Matrix of conglomerate is sand to silty sand, not cemented, very crumbly.
At the time of installation, the Field Geologist names the boring MWB-2. The designation was changed to ESI-2 to be consistent with previous on-site drilling.

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 2 OF 9
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
9	40	100			M					
10	45	100		↕ -zone of moderate consolidation, increase in fine grained material.						
11	50	100		-formation is less consolidated.						-Run No. 11 at 1300.
12	55	100		↕ -size of clasts ranges from coarse sand to gravels.						
13	60	100		-range is from gravels to silts. -3" to 4" diameter gravels generally becoming coarser grained.						
14	65	100			W					
15	70	100		-increase in silt and clays.						
16	75	100	>5	-erosional contact -74.5' metamorphic bedrock. Metamorphic Basement: White to light greenish white, large crystals (1/4 - 1/2" diameter) in aphanitic matrix, very decomposed, crystals are hard >5, closely-spaced fractures, hairline width, appear to be closed, core is dry in center.	M to W					
	80									

NOTES: Mud is 50 viscosity.

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 3 OF 9 -
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
17	80	100			M to W					
18	85	100		-87' fractures, open, 1/8" wide, mineralization of fracture surface, hairline fractures are spaced at about 5-6" apart, mineralization along fracture faces.	M to Slt.					
19	90	100								
20	95	100		-zone of high degree of decomposition. -zone of mid degree of decomposition.	W M					
21	100	100		-zone of moderate to high decomposition fractures at 1' spacing, hairline, not open.	M to W				50°	
22	105	100		-more competent rock, slightly weathered, fractures at 6" spacing.					50°	
23	110	100			Slt. to M					Run No. 23 at 1500.
24	115	100		-some foliation of crystals, planes of weakness, rock breaks at planes.	W					
	120			-119.5 zone of high decomposition and clay development.						Run No. 25 at 1530.

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 4 OF 9
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
25	120	100			M					
26	125	100	>5	-zone of high decomposition and clay development, fractures at ~5" to 6".					50°	
27	130	100								-134' stopped at 1600. 10-17-92 Start @ 0800.
28	135	93								
29	140	100								
30	145	100							50° and 90°	
31	150	100	>5	-zone of high decomposition and more clay development. Fractures at 5" to 6", hairline, not open.	M				50°	
32	155	100								
33	160	100								Run No. 33 at 0925.

NOTES:

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 5 OF 9
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
	160									
34	165	70								
35	170	100		-biotite gneiss: fractures at 3" to 6" open to 1/16", good mineralization in fractures. -crystalline: very fractured with very good mineralization and red clay development decomposed.	M W				50°	-0950 - driller stops to check if core barrel is correct. Start 1100.
36	175	100								
37	180	100		-very fractured, very good clay development, mineralization, well fractured.	W					
38	185	100		-biotite gneiss: green grey, very fractured. -crystalline: good clay development, very fractured.	W					
39	190	100		-187' biotite gneiss: fractured, good clay development, very decomposed, limonite fractures appear open.						-Stop 1300 to mix new mud and get load of water. Start 1350.
40	195	100								
41	200	100								

NOTES:

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 6 OF 9
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
	200			-biotite gneiss: very fractured, clay development, mineralization.	W	▨			50°	
42	205	100		-203': infilling of fracture with quartz, very mineralized fractures spaced at 6" to 1' apart.		▨				
43	210	100				▨				
44	215	100		↓ -213': green and red clay development in fracture.		▨				
45	220	100		-217.5': green and red clay development.		▨				
46	225	100		biotite gneiss: red and green clay development, less fracturing than above, decomposed rock.		▨			50°	-Run 46 at 1450.
47	230	100		↓ -absence of biotite and dark green matrix, light colored crystalline igneous. Light green mineralization.		▨				
48	235	100				▨				
49	240	100		-more competent core, still some degree of fissibility. Fracture faces are altered.		▨				

NOTES:

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 7 OF 9
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
	240				W				50°	
50	245	100		-increased green and red clay development.						
51	250	100		-highly mineralized fractured zone. -decreasing fracturing. Still high to mid degree of alteration.	W					Run No. 51 at 1610. Stopped at 1630. 10/18/92.
52	255	100		-becoming more decomposed and altered, less fracturing at 3" to 6" intervals.						
53	260	100								
54	265	100		-brecciated gouge. -more competent rock, very hard and consolidated, less weathered and fractured.						
55	270	100		-very fractured and altered zone, fractures air tight but not cemented closed.						
56	275	100		-gneiss: very fractured and altered zone, green and red mineralization, rock is friable along foliation.	W					
	280									

NOTES:

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 8 OF 9
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
57	280	100		-gneiss: less fracturing and alteration.	W					
58	285	100		-intensely fractured zone, good to moderate alteration, red clay, green clay, friable.						
59	290	100								
60	295	100								-Run No. 60 at 1205.
61	300	100		-intensely fractured, good clay development, friable.	M to W					Center of core appears to be slightly wet(?)
62	305	100		-304.5': zone of intense red clay development, alteration parameters throughout.	W					
63	310	100								
64	315	100		-increase in green clay alteration.						
	320									

NOTES:

VISUAL CLASSIFICATION OF ROCK

PROJECT NUMBER: 91-296	PROJECT NAME: GFOC - Mesquite Regional Landfill	
BORING NUMBER: ESI-2	ELEVATION: ~560 feet above mean sea level	DATE STARTED: 10-16-92
COORDINATES: Southwest Corner at Section 18, T135, R19E		DATE COMPLETED: 10-18-92
DRILLING METHODS: Mud Rotary Core		PAGE 9 OF 9
CORE SIZE: 2.5" HQWL	ENG./GEO. R. Puga	GWL AT HRS.

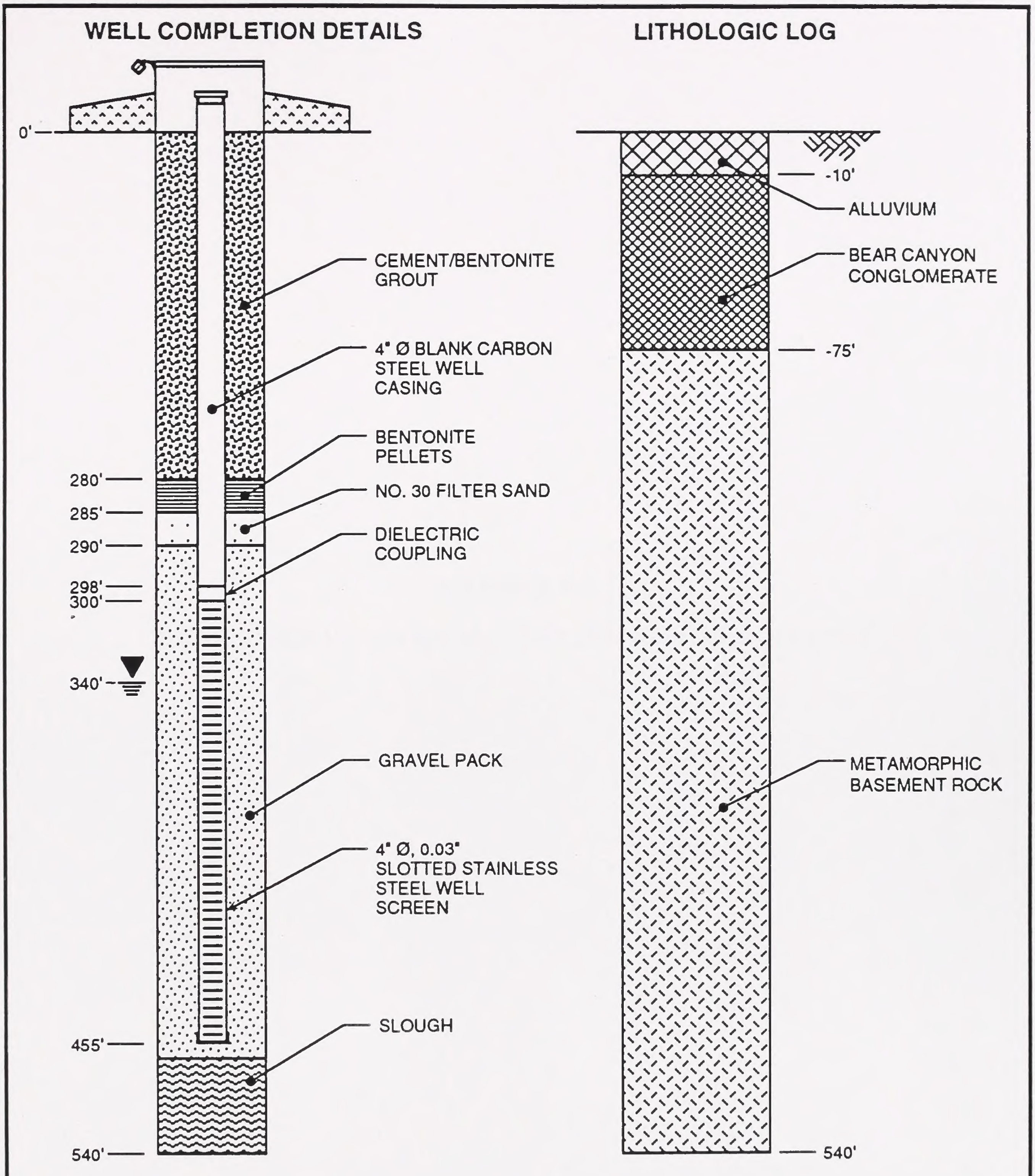
RUN NUMBER	DEPTH (FT)	% RECOVERED	HARDNESS	DESCRIPTION	WEATHERING	PROFILE	JOINTING GRAPHIC	JOINTING JTS/( )	JOINTING DIP	REMARKS
65	320	100			W	▨				
66	325	100		-gneiss: intensely altered to red and green clays in fracture face, very fractured, wet (?) -cutting shows at trace of moisture in center of core.		▨				
67	330	100				▨				
68	335	100		-333': zone of intense red clay alteration, secondary green clay alteration.		▨				-Mud viscosity at 36.
69	340	100				▨				
70	345	100				▨				-Mud viscosity at 34.
71	350	100				▨				
72	355	100		-TD = 354 feet.						
	360									

NOTES: Mud viscosity has been dropping.
TD = 354 feet at 1630.

APPENDIX F.5

LITHOLOGIC LOG AND WELL COMPLETION DETAILS OF LGW-1

91-296HARF-02 REV.08/31/93



NOTE: At the time of installation the field geologist named the well MWB-2. Its designation was changed to LGW-1 to be consistent with the monitoring well designation program.

NOT TO SCALE

FIGURE F.5-1

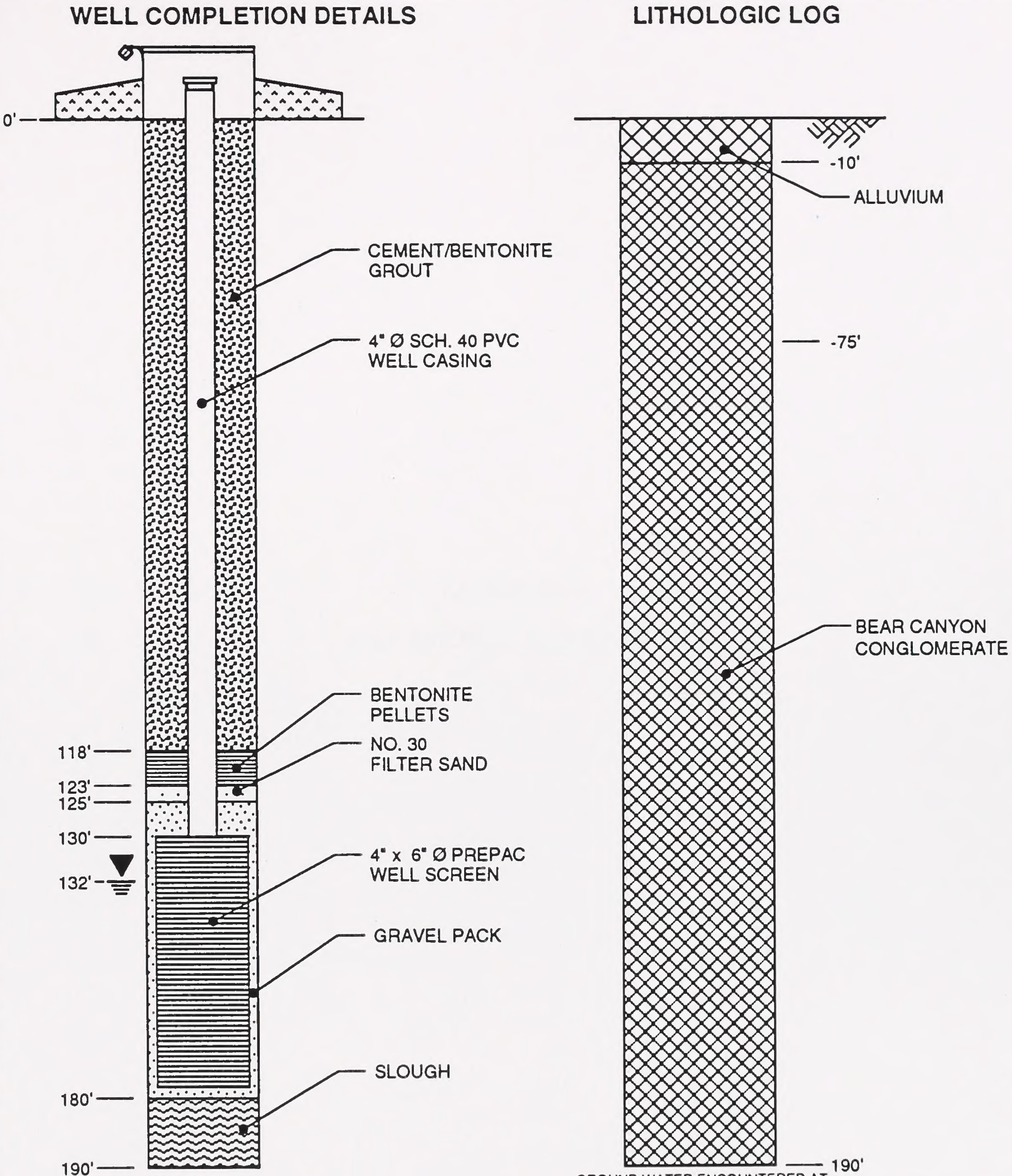
LITHOLOGIC LOG AND WELL COMPLETION DETAILS OF LGW-1

MESQUITE REGIONAL LANDFILL

APPENDIX F.6

LITHOLOGIC LOG AND WELL COMPLETION DETAILS OF LGW-2

91-296HARF-03 REV.08/31/93



GROUND WATER ENCOUNTERED AT 140 FEET BELOW SURFACE

NOTE: At the time of installation the field geologist named the well MWB-1. Its designation was changed to LGW-2 to be consistent with the monitoring well designation program.

NOT TO SCALE

FIGURE F.6-1

LITHOLOGIC LOG AND WELL COMPLETION DETAILS OF LGW-2

MESQUITE REGIONAL LANDFILL

APPENDIX G

HELP MODEL CALCULATIONS

APPENDIX G

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP) COMPUTER PROGRAM(1)

1. The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of landfills. The model accepts climatologic, soil, and design data and utilizes a solution technique that accounts for the effects of surface storage, runoff, infiltration, percolation, evapotranspiration, soil moisture storage, and lateral drainage. The program was developed to facilitate rapid estimation of the amounts of runoff, drainage, and leachate that may be expected to result from the operation of a wide variety of landfill designs.

2. The following parameters were used for the Mesquite Regional Landfill (see Attachment G):

   - Precipitation: Based on site-specific data.
   - Runoff (inches): Assumed none; all precipitation would infiltrate (conservative).
   - Solar Radiation: Default for Yuma, Arizona data.
   - Maximum Leaf Area Index: Assume none (bare ground).
   - Temperature: Based on site-specific data.
   - Growing Season: Default using Yuma, Arizona data.
   - Other Climatological: Default using Yuma, Arizona data.

   Yuma, Arizona was selected for default values because of its proximity (6.0 miles) to the site and is in the same climatological classification (low desert region).

   The conclusion reached by the HELP model for the above parameters is that evaporation rate exceeds infiltration rate, which results in a reduction in moisture in the waste as opposed to an increase due to infiltration.

---

(1) *The Hydrologic Evaluation of Landfill Performance (HELP) Model Volume 1.* User's Guide For Version 1. By P.R. Schroeder, et al. August, 1983.

ATTACHMENT G

```
*****************************************************************************
*****************************************************************************

  ARID LANDFILL
  MESQUITE MINE, IMPERIAL COUNTY
  JANUARY 23,1992

*****************************************************************************
*****************************************************************************



                                  LAYER  1
                                  --------

                         VERTICAL PERCOLATION LAYER
    THICKNESS                          =       6.00 INCHES
    POROSITY                           =       0.4000 VOL/VOL
    FIELD CAPACITY                     =       0.2000 VOL/VOL
    WILTING POINT                      =       0.0500 VOL/VOL
    INITIAL SOIL WATER CONTENT         =       0.2500 VOL/VOL
    SATURATED HYDRAULIC CONDUCTIVITY   =       0.000010000000 CM/SEC



                           GENERAL SIMULATION DATA
                           -----------------------

    SCS RUNOFF CURVE NUMBER            =       80.00
    TOTAL AREA OF COVER                =   871200. SQ FT
    EVAPORATIVE ZONE DEPTH             =       18.00 INCHES
    POTENTIAL RUNOFF FRACTION          =        0.000000
    UPPER LIMIT VEG. STORAGE           =        2.4000 INCHES
    INITIAL VEG. STORAGE               =        1.5000 INCHES
    INITIAL SNOW WATER CONTENT         =        0.0000 INCHES
    INITIAL TOTAL WATER STORAGE IN
      SOIL AND WASTE LAYERS            =        1.5000 INCHES

                SOIL WATER CONTENT INITIALIZED BY USER.


                             CLIMATOLOGICAL DATA
                             -------------------

    USER SPECIFIED RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
    SOLAR RADIATION FOR      YUMA                 ARIZONA
```

ATTACHMENT G
(Continued)

```
     MAXIMUM LEAF AREA INDEX               = 0.00
     START OF GROWING SEASON (JULIAN DATE) =   48
     END OF GROWING SEASON (JULIAN DATE)   =  364


            NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

    JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
    -------     -------     -------     -------     -------     -------

     56.80       59.60       64.10       74.00       75.80       86.30
     91.40       89.40       86.60       78.10       65.80       58.00



***********************************************************************

                      MONTHLY TOTALS FOR YEAR 1989
-----------------------------------------------------------------------

                         JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                         ------- ------- ------- ------- ------- -------

PRECIPITATION (INCHES)     0.00    0.00    0.00    0.00    0.00    0.00
                           0.01    0.00    0.00    0.00    0.00    0.00

RUNOFF (INCHES)           0.000   0.000   0.000   0.000   0.000   0.000
                          0.000   0.000   0.000   0.000   0.000   0.000

EVAPOTRANSPIRATION        1.122   0.000   0.000   0.000   0.000   0.000
     (INCHES)             0.009   0.000   0.000   0.000   0.000   0.000

PERCOLATION FROM         0.0786  0.0000  0.0000  0.0000  0.0000  0.0000
  LAYER  1 (INCHES)      0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

***********************************************************************



***********************************************************************

                       ANNUAL TOTALS FOR YEAR 1989
-----------------------------------------------------------------------
                                     (INCHES)    (CU. FT.)    PERCENT
                                     --------    ---------    -------
  PRECIPITATION                        0.01          726.     100.00

  RUNOFF                               0.000           0.       0.00

  EVAPOTRANSPIRATION                   1.132        82147.    ******

  PERCOLATION FROM LAYER  1            0.0786        5704.    785.70

  CHANGE IN WATER STORAGE             -1.200       -87126.    ******

  SOIL WATER AT START OF YEAR          1.50        108900.

  SOIL WATER AT END OF YEAR            0.30         21774.
  SNOW WATER AT START OF YEAR          0.00            0.

  SNOW WATER AT END OF YEAR            0.00            0.

  ANNUAL WATER BUDGET BALANCE          0.00            0.      0.00

***********************************************************************




***********************************************************************

                    MONTHLY TOTALS FOR YEAR 1990
-----------------------------------------------------------------------

                        JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                        ------- ------- ------- ------- ------- -------

PRECIPITATION (INCHES)   0.00    0.00    0.00    0.00    0.00    0.00
                         0.08    0.10    0.01    0.00    0.00    0.00

RUNOFF (INCHES)          0.000   0.000   0.000   0.000   0.000   0.000
                         0.000   0.000   0.000   0.000   0.000   0.000

EVAPOTRANSPIRATION       0.000   0.000   0.000   0.000   0.000   0.000
     (INCHES)            0.080   0.078   0.032   0.000   0.000   0.000

PERCOLATION FROM         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  LAYER  1 (INCHES)      0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

***********************************************************************



***********************************************************************

                      ANNUAL TOTALS FOR YEAR 1990
-----------------------------------------------------------------------
                                     (INCHES)    (CU. FT.)    PERCENT
                                     --------    ---------    -------
  PRECIPITATION                        0.19        13794.     100.00

  RUNOFF                               0.000           0.       0.00

  EVAPOTRANSPIRATION                   0.190       13793.      99.99

  PERCOLATION FROM LAYER  1            0.0000          0.       0.00

  CHANGE IN WATER STORAGE              0.000           1.       0.01

  SOIL WATER AT START OF YEAR          0.30        21774.

  SOIL WATER AT END OF YEAR            0.30        21775.

  SNOW WATER AT START OF YEAR          0.00            0.

  SNOW WATER AT END OF YEAR            0.00            0.
```

```
   ANNUAL WATER BUDGET BALANCE          0.00             0.        0.00

*******************************************************************************

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                        MONTHLY TOTALS FOR YEAR 1991
-------------------------------------------------------------------------------

                           JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                           ------- ------- ------- ------- ------- -------

PRECIPITATION (INCHES)      0.01    0.01    0.02    0.00    0.00    0.00
                            0.00    0.14    0.09    0.00    0.00    0.01

RUNOFF (INCHES)             0.000   0.000   0.000   0.000   0.000   0.000
                            0.000   0.000   0.000   0.000   0.000   0.000

EVAPOTRANSPIRATION          0.010   0.004   0.026   0.000   0.000   0.000
      (INCHES)              0.000   0.051   0.099   0.081   0.000   0.010

PERCOLATION FROM            0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
  LAYER  1 (INCHES)         0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

*******************************************************************************



*******************************************************************************

                         ANNUAL TOTALS FOR YEAR 1991
-------------------------------------------------------------------------------
                                     (INCHES)     (CU. FT.)     PERCENT
                                     --------     ---------     -------
  PRECIPITATION                        0.28         20328.      100.00

  RUNOFF                               0.000            0.        0.00

  EVAPOTRANSPIRATION                   0.280        20328.      100.00

  PERCOLATION FROM LAYER  1            0.0000           0.        0.00

  CHANGE IN WATER STORAGE              0.000            0.        0.00

  SOIL WATER AT START OF YEAR          0.30         21775.

  SOIL WATER AT END OF YEAR            0.30         21775.

  SNOW WATER AT START OF YEAR          0.00             0.

  SNOW WATER AT END OF YEAR            0.00             0.

  ANNUAL WATER BUDGET BALANCE          0.00             0.        0.00
```

ATTACHMENT G
(Continued)

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*******************************************************************************

    AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1989 THROUGH 1991
-------------------------------------------------------------------------------

                         JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                         ------- ------- ------- ------- ------- -------
  PRECIPITATION
  -------------
    TOTALS                 0.00    0.00    0.01    0.00    0.00    0.00
                           0.03    0.08    0.03    0.00    0.00    0.00

    STD. DEVIATIONS        0.01    0.01    0.01    0.00    0.00    0.00
                           0.04    0.07    0.05    0.00    0.00    0.01

  RUNOFF
  ------
    TOTALS                 0.000   0.000   0.000   0.000   0.000   0.000
                           0.000   0.000   0.000   0.000   0.000   0.000

    STD. DEVIATIONS        0.000   0.000   0.000   0.000   0.000   0.000
                           0.000   0.000   0.000   0.000   0.000   0.000

  EVAPOTRANSPIRATION
  ------------------
    TOTALS                 0.377   0.001   0.009   0.000   0.000   0.000
                           0.030   0.043   0.044   0.027   0.000   0.003

    STD. DEVIATIONS        0.645   0.002   0.015   0.000   0.000   0.000
                           0.044   0.040   0.050   0.047   0.000   0.006

  PERCOLATION FROM LAYER  1
  -------------------------
    TOTALS                 0.0262  0.0000  0.0000  0.0000  0.0000  0.0000
                           0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

    STD. DEVIATIONS        0.0454  0.0000  0.0000  0.0000  0.0000  0.0000
                           0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

*******************************************************************************



*******************************************************************************

  AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1989 THROUGH 1991
-------------------------------------------------------------------------------
                                     (INCHES)         (CU. FT.)     PERCENT
                                 ----------------    -----------    -------

  PRECIPITATION                    0.16   ( 0.137)       11616.     100.00

  RUNOFF                           0.000  ( 0.000)           0.       0.00
```

```
EVAPOTRANSPIRATION           0.534  ( 0.520)      38756.    333.64

PERCOLATION FROM LAYER  1    0.0262 ( 0.0454)      1901.     16.37

CHANGE IN WATER STORAGE     -0.400  ( 0.693)     -29042.    ******

***********************************************************************




***********************************************************************

          PEAK DAILY VALUES FOR YEARS 1989 THROUGH 1991
    ---------------------------------------------------------------
                                             (INCHES)    (CU. FT.)
                                             --------    ---------
     PRECIPITATION                             0.10        7260.0

     RUNOFF                                    0.000          0.0

     PERCOLATION FROM LAYER  1                 0.0108       781.9

     SNOW WATER                                0.00           0.0


     MAXIMUM VEG. SOIL WATER (VOL/VOL)             0.2500

     MINIMUM VEG. SOIL WATER (VOL/VOL)             0.0498

***********************************************************************




***********************************************************************

             FINAL WATER STORAGE AT END OF YEAR 1991
    ---------------------------------------------------------------
              LAYER        (INCHES)        (VOL/VOL)
              -----        --------        ---------
                1            0.30            0.0500

             SNOW WATER      0.00

***********************************************************************
***********************************************************************
```

APPENDIX H

ANALYSIS OF TRIPLE-COMPOSITE LINER PERFORMANCE

H.1 TRIPLE-COMPOSITE LINER
H.2 LCRS CALCULATIONS

APPENDIX H.1

TRIPLE-COMPOSITE LINER

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H.3-3 Worst-Case Accident Risk Comparison

1.0 INTRODUCTION

1. This appendix describes the ground water protection system designed for the proposed Mesquite Regional Landfill. This ground water protection system is designed to prevent ground water contamination due to migration of either leachate or landfill gas (LFG) from the landfill. The system includes the following primary components:

   - Controls for management and collection of liquids or gases that form within the landfill, without allowing them to migrate into the subsurface.
   - Monitoring for early identification of liquids or gases which could migrate and eventually contaminate ground water.
   - Response procedures to quickly mitigate conditions which could result in migration and eventual contamination of ground water.

   The underlying philosophy for the design is to provide redundancies in the control and monitoring systems to assure a high level of confidence that potential migrating liquids or gases can be prevented from moving out of the landfill and contaminating ground water. Table H.1-1 summarizes the redundant systems to be provided for the initial landfill disposal segments. The response procedures are designed to mitigate conditions which create the low potential for migration of liquids or gases into the ground water long before any real threat exists.

2. The natural environment at the proposed project site has features that protect ground water from contamination. One feature is the arid climate that offers little rain that can fall on the proposed landfill. Only 4 inches of rain would fall on average each year, in comparison with an evaporation rate of approximately 100 inches. Additionally, ground water is deep below the planned disposal elevation. In the initial cell, where these control and monitoring systems are expected to be most extensive, the vadose (unsaturated) zone is about 340 feet thick. The majority of this vadose zone consists of Bear Canyon Conglomerate formation, which has a low hydraulic conductivity of 10^{-6} cm/sec or less. The shallowest depth to ground water is about 140 feet in the northwest corner of the landfill. Disposal operations at that location not expected to begin until after about 80 years of operating experience.

3. Section 2.0 describes the characteristics of leachate and LFG which would potentially occur within the landfill. These include consideration of the: (1) rates of leachate and LFG generation which could potentially occur; and (2) chemical composition which could be expected for each.

4. The Section 3.0 discussion is directed toward the expected performance of the basic leachate and LFG control systems. For leachate control, consideration includes landfill:
   - Development and operational procedures.
   - Closure procedures.

   For LFG control, this includes the horizontal collector system, which will be incorporated into the landfill from the beginning of operations. Each system is being designed to include redundant elements aimed toward maintaining a very low potential for migration of leachate or LFG to occur.

5. The potential migration rate and fate of leachate or LFG, if any were to migrate beyond the basic control systems, is also discussed in Section 3.0. This discussion focuses on conditions at the first disposal segment, which would be in the southwest corner of the landfill. This area is emphasized because:
   - It is located at the downgradient portion of the landfill.
   - The RWQCB desires assurance that special degrees of protection and monitoring are applied to the initial development of large regional landfills. This would provide a high level of assurance that the anticipated behavior is being realized as early as possible during landfill development.

   When the performance is demonstrated to be satisfactory, it may be possible to reduce some monitoring requirements at future segments during mandatory 5-year reviews of the Waste Discharge Order (WDO).

2.0 POTENTIAL CONTAMINANT SOURCES

1. The two potential contaminant sources from the proposed Mesquite Regional Landfill would be: (1) leachate generated due to liquids migrating through the soil cover and waste materials; and (2) LFG generated due to the biological degradation of organic material (e.g., cellulose) in the waste. The expected generation rates and composition of these fluids are described in the following sections.

2.1 LEACHATE

1. Because liquid wastes would not be disposed at the proposed Mesquite Regional Landfill, potential leachate generation would only be associated with rain which may fall onto and infiltrate through the compacted municipal solid waste (MSW) residue. It is not anticipated that leachate will be generated for most of the operating life nor at closure for each disposal segment due to the arid climate in the site area.

2. The primary exception would be associated with the potential that an infrequent rainstorm event would occur on a lined segment before any waste has been placed. In that event, a portion of the rain falling directly onto the liner and protective system would flow into the leachate collection and recovery system (LCRS) for a period of hours to a few days. This relatively clean water would be mixed with a small portion of runoff from the working face of the first layer, which could potentially contain some contaminants. The combined liquids from this unusual segment startup condition would be highly diluted with respect to leachate which is generated by passage of rainwater through a substantial thickness of trash such as occurs at landfills in wetter climates.

3. The potential for leachate to occur at the proposed Mesquite Regional Landfill would decrease quickly as the first 20-foot layer of MSW residue and related daily soil cover is placed above the liner system. Appendix G of this Hydrogeologic Assessment Report contains the results of U.S. EPA's Hydrologic Evaluation of the Landfill Performance (HELP) model as applied to the Mesquite Regional Landfill site conditions. The model results show that the arid site conditions would generally cause evaporation to exceed infiltration for even the thin daily soil cover. Even minor amounts of precipitation which could occasionally fall directly onto a small operating disposal face would not result in downward migration. Instead, the moisture would be retained in the top several inches of the otherwise dry trash.

4. The site's "net water loss" condition is confirmed by geotechnical studies conducted by SHB (1984), and recent test pits excavated by Environmental Solutions, Inc. shortly after the unusually rainy period in early 1993. SHB (1984) showed that existing subsurface moisture is lower than field capacity. Field capacity is the moisture content limit of a medium that must be exceeded before a downward migration of liquid can occur. Hence, the desert floor appears to be experiencing soil pore loss of water as opposed to infiltration. The test pits excavated by Environmental Solutions, Inc. in February 1993 showed surface soil exposed to recent heavy rain was only slightly moist at about 8 inches below the surface of the desert floor, and appeared to be completely unaffected by the recent rains at a depth of 12 inches.

5. The potential for precipitation to generate leachate above the liner system would decrease as each additional 10-foot lift of MSW residue is disposed. For example, even if a small amount of water from an extreme rainfall event infiltrated through the daily cover, it would have to wet the entire volume of waste between the surface and liner to the material's field capacity in order for downward migration to reach the liner. Prior to closure, this dry trash would be as much as 400 feet thick.

6. Finally, when the landfill is closed, it will be covered with either a minimum of 7 feet of compacted soil at slope areas, or flexible membrane liner (FML) and soil combination on the flatter top areas. The infiltration calculations presented in Appendix G show that these provisions will essentially eliminate the potential for any infiltration to occur in even the highest lifts of MSW residue. Thus, at closure, there will be no potential for leachate to be generated that can reach the liner system.

7. In summary, the following list indicates the small potential for leachate to be generated at various development stages at the proposed Mesquite Regional Landfill:

PERIOD	POTENTIAL FOR LEACHATE
• Approximate 3- to 6-month period when the first MSW residue lift is being placed at any segment.	• Relatively clean infiltration water will reach the LCRS if an infrequent desert thunderstorm occurs on portions of liner system not covered by waste.
• After completion of first 20 feet of MSW residue placement at any segment.	• Very small.
• From the first 20-foot thickness to the approximate 400-foot total landfill height.	• Essentially zero.
• After closure.	• Essentially zero.

2.2 LANDFILL GAS

1. The Air Quality Technical Report (Environmental Solutions, Inc., March 1993) discusses the rates at which LFG will be generated as a whole. This generation will occur in spite of the dry site conditions because the MSW residue (e.g., food wastes) contains sufficient moisture to result in the long-term biodegradation of a large portion of the organics in MSW residue. The Air Quality Technical Report also discusses how the LFG generation rate for the entire landfill will gradually rise to a maximum value on the last day that MSW residue is landfilled in about 2093 and that it will then decline to a small value over an approximate 30-year period as illustrated in Figure H.2-1.

2. The rate of LFG generation from the bottom landfill lift at any individual segment, where the gas has the potential to reach the liner, will be much less and will occur for a much shorter time than for the landfill as a whole. For comparison, the estimated generation rate for the

bottom 50 feet of the first, southwest landfill segment is also shown in Figure H.2-1. The peak LFG generation rate would occur in the bottom 50 feet about 15 months after initial disposal. Afterwards, the generation rate for that specific volume would decrease, even though the LFG generation rate for the overall landfill would continue to increase. The rate would decrease to 10 percent of the peak rate in about 34 years for the bottom 50 feet of any segment. By that time, the gas collection system within that portion of the landfill would potentially have more than ten times the capacity required to collect LFG from the nearby MSW residue.

3. LFG consists mostly of carbon dioxide and methane nearly in equal amounts. Neither of these two main components represents a threat to ground water quality. Carbon dioxide is nontoxic. The primary threat of methane is its potential to explode if it collects in enclosed structures in concentrations between 5 and 15 percent. This threat would not occur at the Mesquite Regional Landfill because structures would not be located near the landfilled MSW residue. The constituents of concern with regard to ground water quality are the trace volatile organic compounds (VOCs) which migrate along with LFG. These VOCs could dissolve in ground water exposed to LFG. For MSW residue, these constituent concentrations would be low, but could still affect ground water quality because of the length of time of potential exposure if the LFG were not appropriately controlled.

4. Figures H.2-2 illustrates the horizontal well system which would be installed throughout the landfill to collect LFG for destruction at a flare station or for processing in an energy recovery system. The functioning of this system as a control element to prevent the potential for ground water contamination due to LFG migration into the subsurface is discussed in Section 3.3.1.

3.0 ESTIMATED CONTROL SYSTEM PERFORMANCE

3.1 GENERAL

1. The following redundant control systems (see Figures 2.6 and 2.7, and Section 2.2 of the Hydrogeological Assessment Report) are provided in the first segment design to eliminate the potential for ground water to be contaminated:
   - Leachate Related
     - The MSW residue is compacted and covered with daily, intermediate and final cover.
     - A triple composite liner is provided to minimize the potential for leachate to enter the subsurface, if leachate were to be generated.

  - An LCRS system is provided above the triple composite liner to limit leachate hydrostatic head to a low value on top of the low permeability liner system. Calculations discussed in this section are based on a maximum head of 1 foot above the composite liner. In actuality, the head, if any, is likely be only a fraction of this value.
  - A secondary LCRS and FML layer is provided in the zones with the greatest potential for leachate to occur. This layer acts as a vadose zone monitor to evaluate the performance of the main LCRS and triple composite liner, as well as a redundant leachate control system for areas where higher leachate volumes are anticipated.
- LFG Related
  - A series of horizontal trenches (Figure H.2-2) would be provided in the landfill to collect LFG and maintain a vacuum above the triple composite liner system.
  - Backup blower systems and emergency power generation would be maintained onsite to assure that the LFG collection system, especially the bottom portions of this collection system, operates continuously.
  - The triple composite liner system would act as a barrier to downward migration in the event a vacuum was not maintained above.

2. The following sections describe calculations performed to evaluate the anticipated performance of each ground water protection system component.

3.2 LEACHATE RELATED

3.2.1 Compacted MSW Residue and Cover Systems

1. Section 2.0 discussed the site conditions and low precipitation which virtually assure that leachate will not occur after the first few lifts of MSW residue are disposed in a segment. Appendix G provides results of HELP model analyses which confirm that evaporation rates would exceed infiltration rates for daily and intermediate soil cover, and for MSW residue itself. The potential for infiltration to occur at the final cover is much less.

3.2.2 LCRS

1. Calculations for the LCRS capacity are provided in Appendix H.2. If the water from a 2-year thunderstorm (0.39 inches per peak hour) were to reach the LCRS, (assuming no water is removed prior to reaching the LCRS through runoff) the flow along a width of 1,500 feet for a segment would be about 6 gallons per minute (gpm). The depth of this flow through 10^{-1} cm/sec gravel above the triple composite liner sloped at 1.3 percent would only be about 2.5 inches as shown in Figure H.3-1 without consideration for the perforated pipes within the LCRS. If a more realistic assumption is made that 70 percent of this rainfall typically would

be removed through runoff, then the infiltration rate through the operations layer would be only 30 percent of the rainfall, and the flow would be reduced from 6 to about 1.8 gpm, with the depth of flow reduced from 2.5 to 0.975 inch. This data shows that the 1 foot of head assumed above the triple composite liner in the next section is conservative.

3.2.3 Triple Composite Liner System Performance

1. The triple composite liner system consists of an FML above and below a clay layer with hydraulic conductivity of 10^{-6} cm/sec, and has several advantages over the more frequently used double composite liner which consists of an FML over a clay layer. One long-term performance advantage of a triple liner is suggested by the work of Daniel and Wu (1993), who discuss difficulties with clay cracking if it loses its moisture. Because the subsurface at the proposed site is naturally dry, it could remove moisture from beneath an unprotected clay liner over time and cause cracking. The underlying FML will prevent this drying (desiccation).

2. Additional performance advantages of the triple composite liner are associated with its ability to restrict leachate or LFG migration due to the following two characteristics:
   - For significant leakage to occur, defects in all three components must be closely aligned. The probability of these defects being closely aligned is minute, as discussed below.
   - Even if defects in the top and bottom FMLs were to be nearly aligned, the seepage rate would be much lower than that which could occur through either a single liner or double composite system because of the low permeability clay layer between the two FMLs.

   These advantages are quantified in the following paragraphs.

3. Studies prepared for the U.S. EPA to evaluate FML performance (Giraud and Bonaparte, 1989a and 1989b) suggest that for design purposes, it is conservative to assume that there could be one 0.45-inch diameter defect for each acre of any synthetic liner. This defect could be caused by material failure, incomplete seam welding, or damage inflicted during liner installation. Hutchison and Ellison (1992) discuss that the 0.45-inch diameter defect per acre estimate should be conservative for sites using modern quality assurance/quality control procedures such as those planned for the Mesquite Regional Landfill. Therefore, the 0.45-inch defect per acre assumption is used for design of Mesquite Regional Landfill ground water protection systems.

4. For direct leakage to occur through the triple composite liner system, the clay layer would have to be defective at the same location as both FMLs. Such a defect is not likely because clay would be constructed with careful control of composition and moisture content, and specifications would require frequent wetting to avoid desiccation cracking. However, to evaluate this possibility, a probabilistic model was developed to determine the likelihood of defects being aligned in both FMLs and the clay. To be conservative, it was assumed that seepage would result if the alignment was within a diameter (D_S) five times larger than the defect ($D = 0.45$ inches) in the FML as illustrated in Part A of Figure H.3-2. The probabilities were calculated of such alignment occurring for: (1) any single acre; and (2) within a 59-acre segment are illustrated in Part B of Figure H.3-2. Considering a value of D_S of five times D, or 2.2 inches, the probability of three defects being aligned is about 3×10^{-13} for any given acre, or 2×10^{-11} for any segment.

5. For comparison, Figure H.3-3 shows the probability of unusual events to occur. This shows that the probability of three liner defects being aligned is less than the potential for a person to be killed by a meteorite.

6. A second performance calculation can be made by assuming that 0.45-inch diameter defects in the two FMLs are approximately aligned with no defects or anomalies in the in between clay layer. For this case the amount of leakage leaving the bottom FML can be estimated by determining the:
   - Amount of leakage which would occur through the defect in the top FML and into the clay layer.
   - Portion of that seepage flow which would occur through the defect in the bottom FML.

   The flow into the clay is estimated using tables of liner leakage provided in Chapter 7 of *Mine Waste Management* (edited by Hutchison and Ellison, 1992). Table 7.8 of that reference indicates that the leakage rate due to a 1 foot head through a 0.45-inch diameter FML defect into 10^{-6} cm/sec soil would be about 1 gallon per acre per day (gpad). This would amount to a flow rate of about 7×10^{-4} gpm.

7. The gradual flow through the 10^{-6} cm/sec clay layer and eventually through the assumed defect in the lower FML would be expected to reach an equilibrium at a very low steady-state rate. Assuming that the two defects are nearly aligned, the steady-state flow would be approximately equal to the flow through the 0.45-inch diameter cylinder of clay (permeability

equals 10^{-6} cm/sec) immediately above the hole in the bottom liner. Considering the conservative hydraulic head of 1 foot in the LCRS, this condition would result in a seepage of less than 10^{-7} gpm, or about 0.0001 gpd.

8. As a final calculation of performance, use of the equation on page 367 of *Mine Waste Management* indicates that the steady-state flow through 0.45-inch diameter defects nearly aligned with 1-foot of 10^{-6} cm/sec clay between would require more than 1,000 and 10,000 continuous years of leakage occurring into a 10^{-5} cm/sec subsurface material to reach depths of 20 and 50 feet, respectively, below the liner system. Over a million years would be required to reach ground water, more than 300 feet below the first landfill segment.

9. The above analyses show that there is an extremely small potential that any leakage could occur through the triple composite liner being designed for the Mesquite Regional Landfill. Also, even in the improbable event a very small amount of leakage occurred, it would not migrate a significant distance during the entire operating life of any segment, or the entire landfill for that matter.

3.3 LFG RELATED

3.3.1 LFG COLLECTION SYSTEM

1. A set of horizontal collectors (see Figure H.2-2) would be used to collect the majority of the generated LFG. The normal spacing is expected to be 250-foot centers horizontally and 50-foot centers vertically. However, the bottom row would be located just 20 feet above the liner system and would be spaced at only 125-foot centers. This arrangement would provide added assurance that a vacuum condition can be maintained immediately above the triple composite liner system, so that there are no pressure conditions which would "push" the LFG into the vadose zone.

2. In the event a positive pressure were to occur at the base of the landfill (e.g., during short-term vacuum system shutdowns) the triple composite liner would function the gas control in a manner similar to that discussed above for leachate. The probability of any LFG escaping through triple composite liner would be extremely small because of the low probability that defects in the three liner components could be aligned. Even if alignment were to occur at the same location for the top and bottom FMLs, the rates of migration would be very small due to the defect size and restriction caused by the 1 foot of nearly saturated clay.

3. As demonstrated for the leachate condition described in Section 3.2.3, the flow of LFG at such a coincidental alignment would not be expected to approach the depth of the underlying vadose zone monitoring system within any reasonable time, in comparison with the 20- to 30-year period that the MSW residual material would be expected to generate LFG for any specific location (see Figure H.2-1). The potential for migration of LFG to ground water is extremely remote even if the vacuum system were not applied for a long period.

4.0 REFERENCES

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TABLE H.1-1

REDUNDANT SYSTEMS TO PREVENT LEACHATE AND LFG MIGRATION MESQUITE REGIONAL LANDFILL(1)(2)

LEAK PREVENTION

- Redundant control systems for the management and collection of leachate and LFG:
    - Cover systems
        - Daily, intermediate and final, that reduce the infiltration of precipitation into the MSW residue.
        - Final cover systems which prevent long-term infiltration of precipitation.
    - Leachate collection and recovery system (LCRS).
    - Horizontal vacuum well LFG collection system throughout the landfill.
- Triple composite liner:
    - 60-mil thick high density polyethylene (HDPE).
    - 1-foot thick clay layer with hydraulic conductivity of 10^{-6} cm/sec.
    - 30-mil thick Very Low Density Polyethylene (VLDPE).

LEAK DETECTION AND MONITORING

- Leachate:
    - Main LCRS above triple composite liner.
    - Second vadose zone LCRS system below triple composite liner at locations of potential maximum flow.
    - Vadose zone wells beneath liner system.
- LFG:
    - Pressure probes at top of bottom soil operations layer.
    - Vadose zone wells beneath liner system.

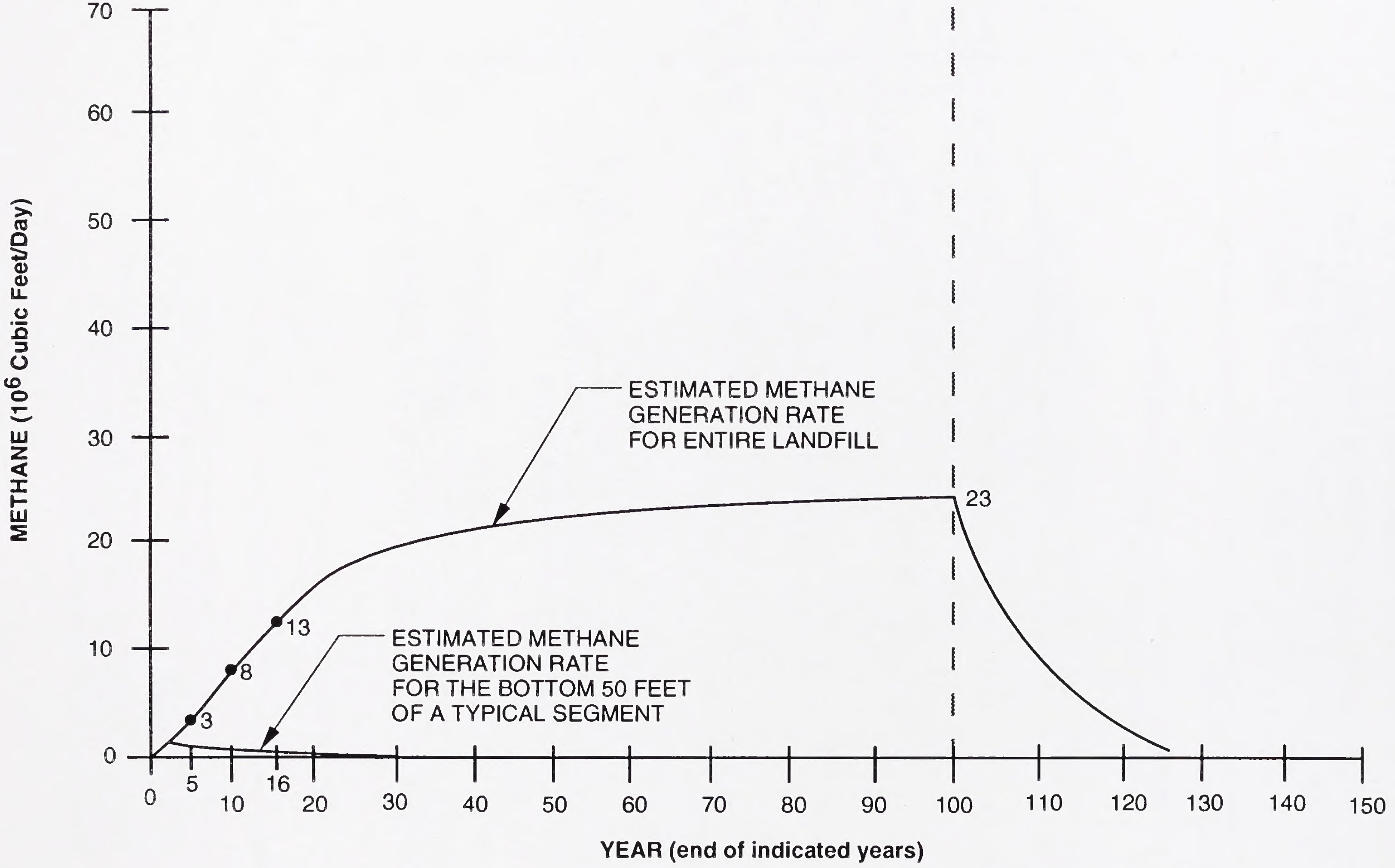
PROCEDURES AVAILABLE TO MITIGATE DETECTED LEAK

- Increase vacuum control for LFG
- Provide thicker intermediate cover layer to prevent infiltration and/or to allow for increased vacuum control of LFG above the liner system.

91-296 (11/15/93/dh)

(1) Individual components and materials may be modified from time to time to suit technological improvements and RWQCB 5-year reviews of system performance.

(2) Ground water monitoring wells are not included in this table, which summarizes redundant procedures to be provided which prevent contamination from reaching ground water.

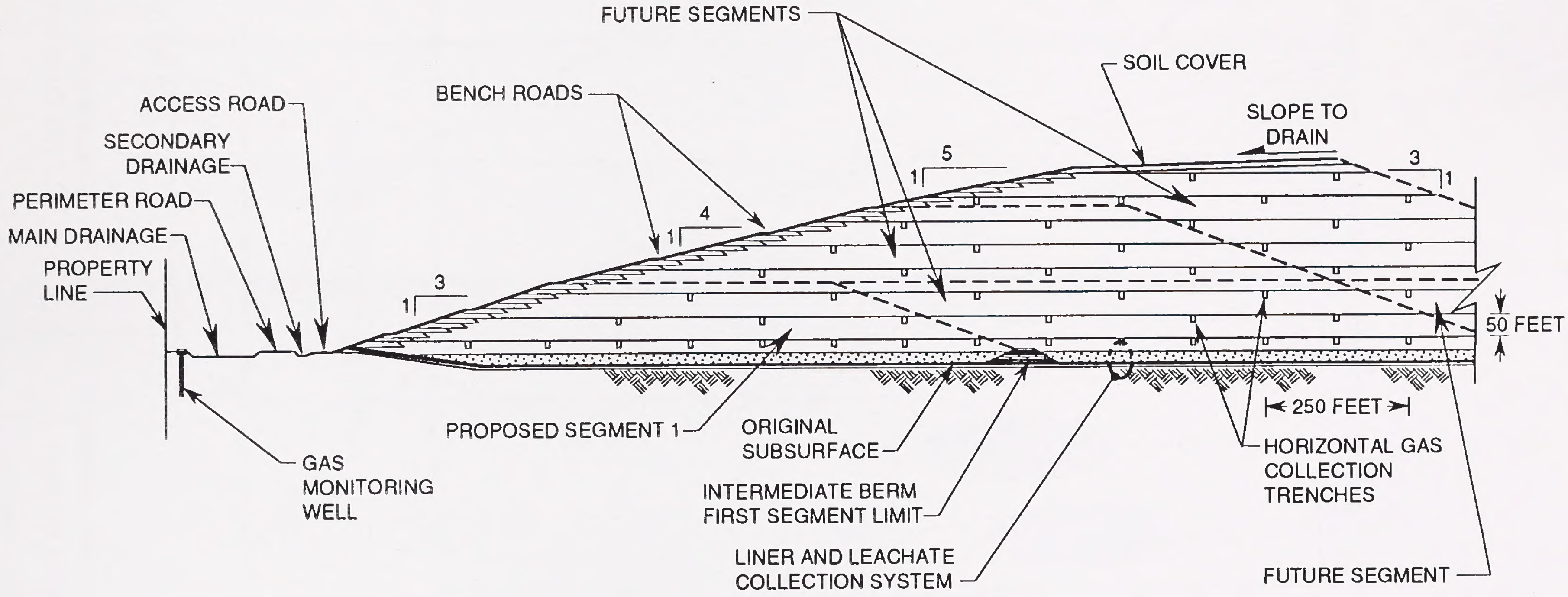


NOTE: METHANE IS THE KEY COMPONENT OF LANDFILL GAS, THOUGH CARBON DIOXIDE IS GENERATED AT APPROXIMATELY THE SAME RATE.

FIGURE H.2-1

ESTIMATED METHANE GENERATION RATE

MESQUITE REGIONAL LANDFILL



NOT TO SCALE

FIGURE H.2-2

EXAMPLE LANDFILL CROSS SECTION WITH COLLECTION GRID

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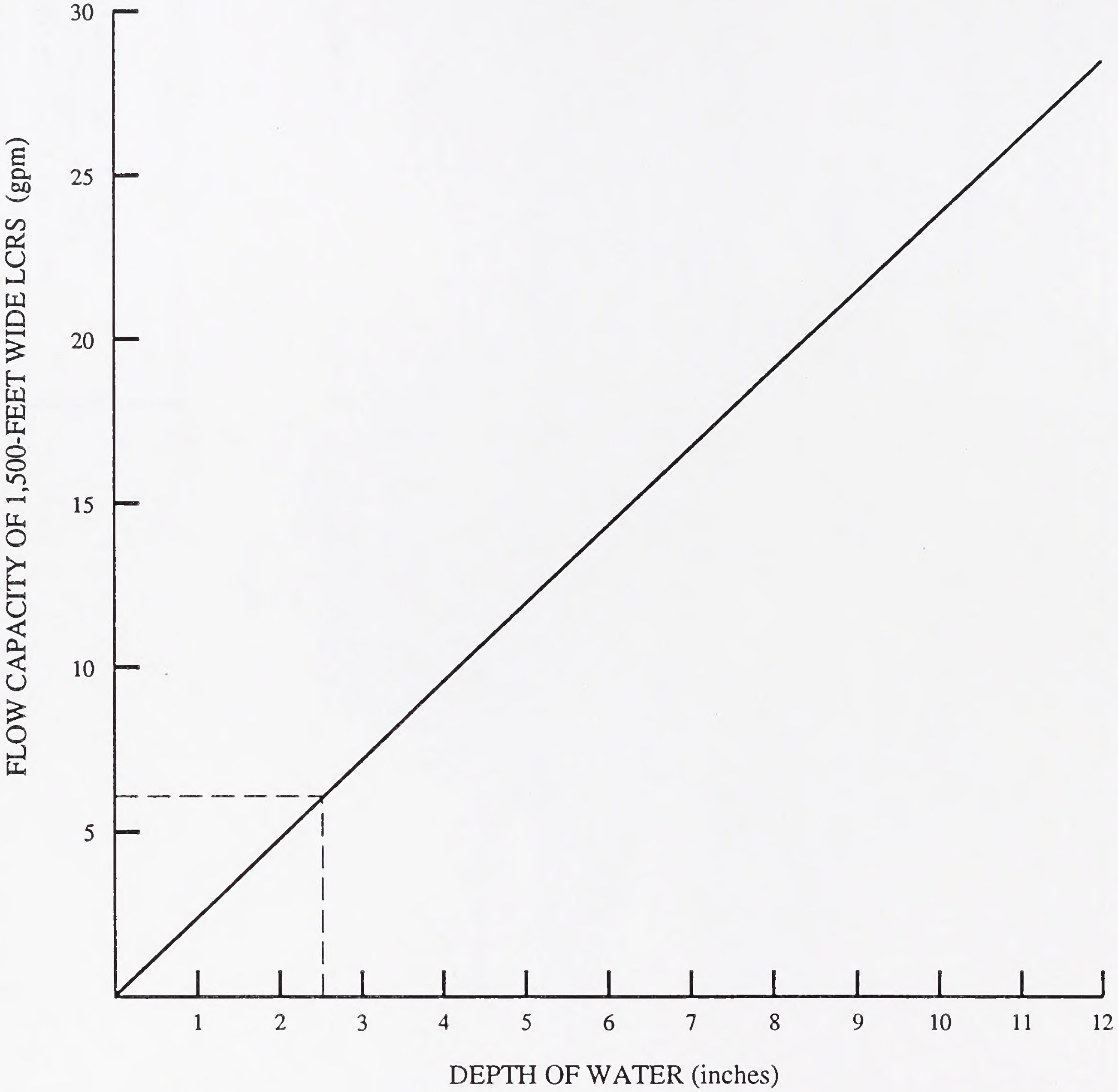

Gravel Hydraulic Conductivity = 10^{-1} cm/sec
Liner Slope = 1.3 Percent
Cross-Flow Width of Segment = 1,500 Feet

FIGURE H.3-1

FLOW CAPACITY OF LCRS GRAVEL LAYER

MESQUITE REGIONAL LANDFILL

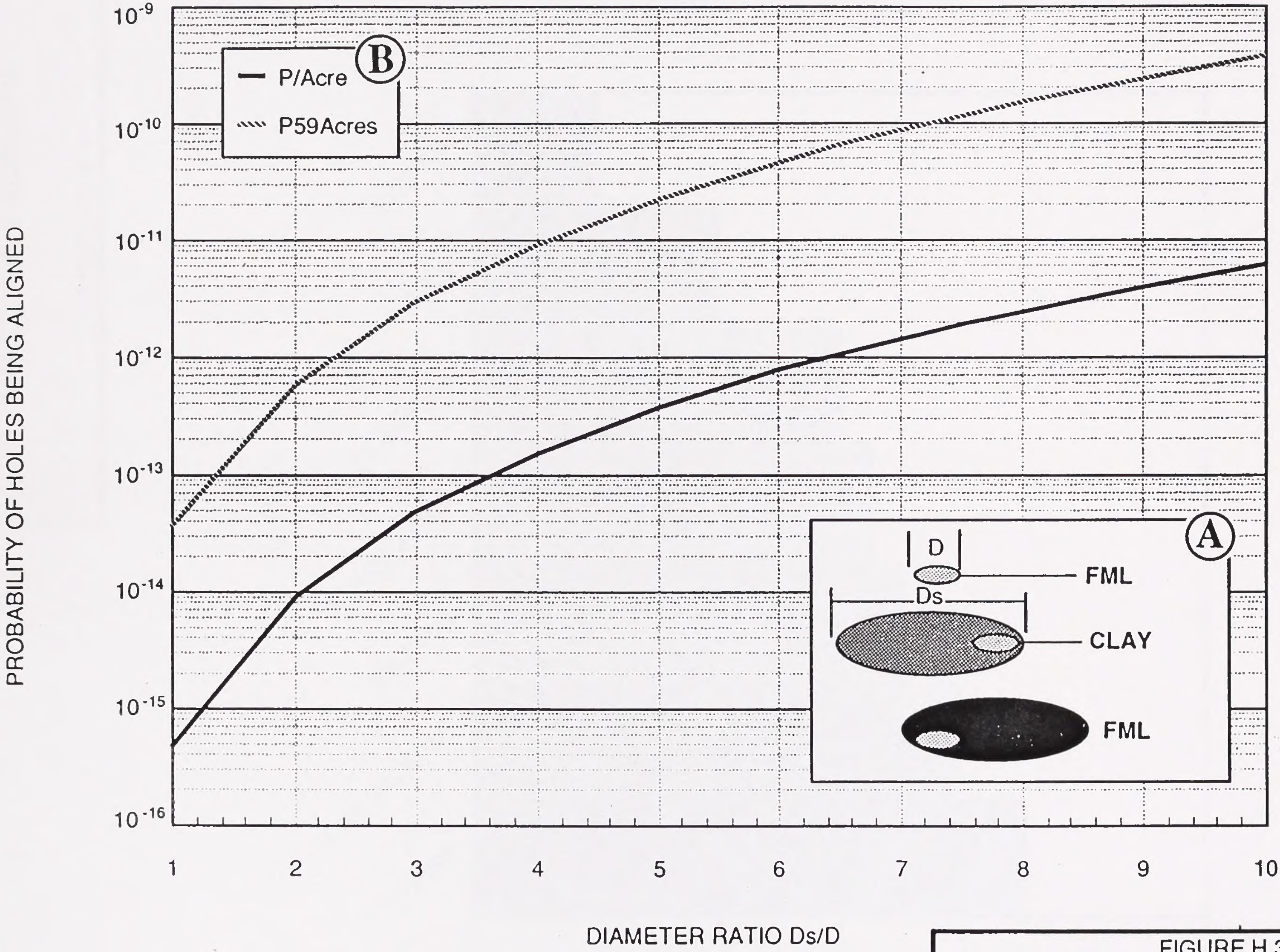

FIGURE H.3-2

PROBABILITY OF
AT LEAST ONE SET OF HOLES
BEING ALIGNED

MESQUITE REGIONAL LANDFILL

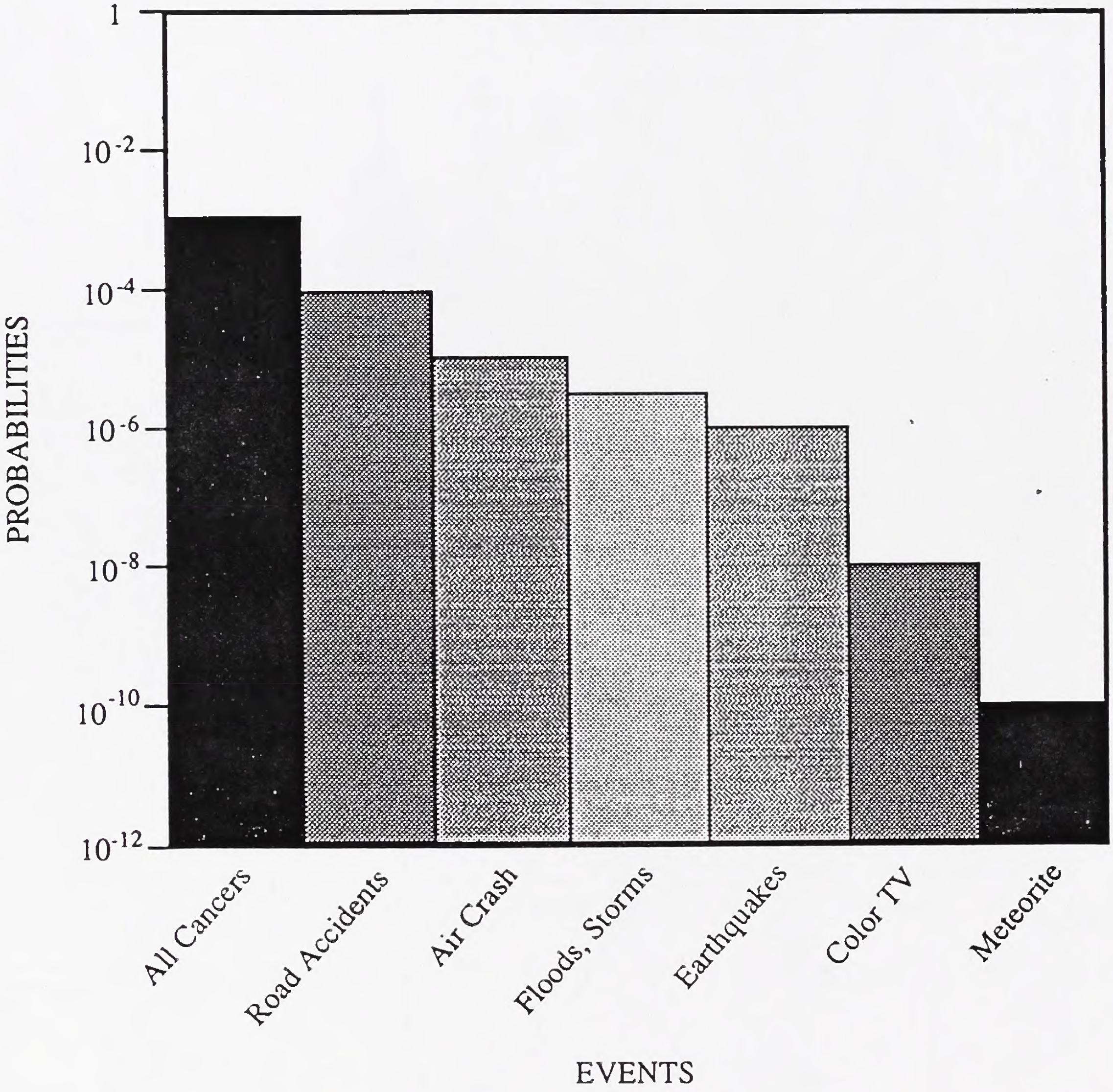

FIGURE H.3-3

WORST-CASE ACCIDENT RISK COMPARISON(1)

MESQUITE REGIONAL LANDFILL

(1)Individual annual risk of death due to event shown. From Technical Report 1612-2, NTS Engineering, 1986.

APPENDIX H.2

LCRS CALCULATIONS

By ______ Date ______ Subject ______ Sheet No. ______ of ______

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CAPACITY OF LEACHATE COLLECTION AND REMOVAL SYSTEM (LCRS)

MESQUITE REGIONAL LANDFILL

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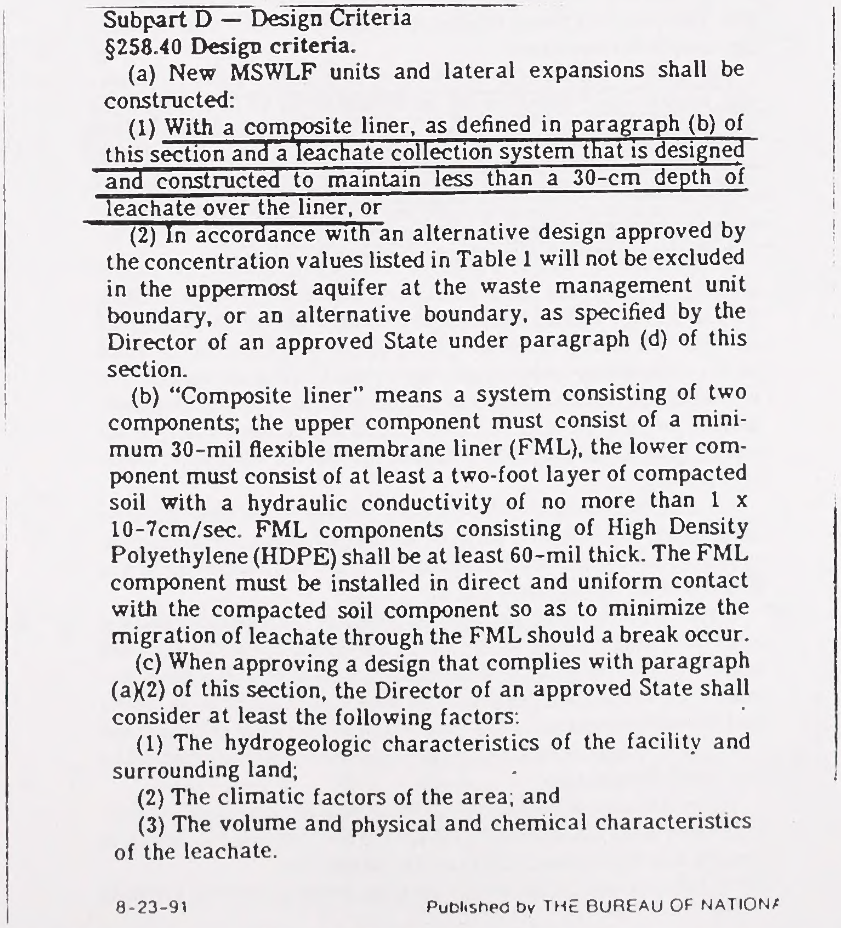
CAPACITY OF LEACHATE COLLECTION AND REMOVAL SYSTEM

OBJECTIVE: EVALUATE THE CAPACITY OF THE LEACHATE COLLECTION AND REMOVAL SYSTEM AS A FUNCTION OF GRAVEL PERMEABILITY AND SLOPES.

CRITERIA

FEDERAL: CFR PART258- CRITERIA FOR CLASSIFICATION OF SOLID WASTE DISPOSAL FACILITIES AND PRACTICES. SUBPART D-DESIGN CRITERIA



Subpart D — Design Criteria

§258.40 Design criteria.

(a) New MSWLF units and lateral expansions shall be constructed:

(1) With a composite liner, as defined in paragraph (b) of this section and a leachate collection system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner, or

(2) In accordance with an alternative design approved by the concentration values listed in Table 1 will not be excluded in the uppermost aquifer at the waste management unit boundary, or an alternative boundary, as specified by the Director of an approved State under paragraph (d) of this section.

(b) "Composite liner" means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible membrane liner (FML), the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1 x 10-7cm/sec. FML components consisting of High Density Polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component so as to minimize the migration of leachate through the FML should a break occur.

(c) When approving a design that complies with paragraph (a)(2) of this section, the Director of an approved State shall consider at least the following factors:

(1) The hydrogeologic characteristics of the facility and surrounding land;

(2) The climatic factors of the area; and

(3) The volume and physical and chemical characteristics of the leachate.

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§ 2543. Leachate Collection and Removal Systems.

(a) Leachate collection and removal systems are required for Class I landfills, surface impoundments, and waste piles; for Class II landfills and surface impoundments; and for Class III landfills which have a liner or accept sewage or water treatment sludge. The systems shall be installed directly above underlying containment features for landfills and waste piles, and installed between the liners for surface impoundments. Leachate collection and removal systems requirements are summarized on Table 4.1. Class II landfills and waste piles which contain only dry wastes (not including nonhazardous solid waste and decomposable waste) may be allowed to operate without leachate collection and removal systems if the discharger demonstrates, based on climatic and hydrogeologic conditions, that leachate will not be formed in, or migrate from, the unit.

(b) Where leachate collection and removal systems are used, they shall be installed immediately above the liner, or between the inner and outer liner of a double–liner system, and shall be designed, constructed, maintained, and operated to collect and remove twice the maximum anticipated daily volume of leachate from the waste management unit.

(c) Regional boards shall specify design and operating conditions in waste discharge requirements to ensure that there is no buildup of hydraulic head on the liner. The depth of fluid in the collection sump shall be kept at the minimum needed to ensure efficient pump operation.

(d) Leachate collection and removal systems shall be designed and operated to function without clogging through the scheduled closure of the waste management unit and during the post–closure maintenance period. The systems shall be tested at least annually to demonstrate proper operation. The results of the tests shall be compared with earlier tests made under comparable conditions.

(e) Leachate collection and removal system shall consist of a permeable subdrain layer which covers the bottom of the waste management unit and extends as far up the sides as possible, (i.e., blanket–type) except as provided in subsection (f) of this section. The collection and removal system shall be of sufficient strength and thickness to prevent collapse under the pressures exerted by overlying wastes, waste cover materials, and by any equipment used at the waste management units.

(f) If a Class III landfill is required to have an artificial liner and receives only permeable waste that allows free drainage of percolating fluid, a dendritic leachate collection and removal system which underlies less than 100 percent of the waste may be allowed. Only wastes which have a permeability which approximates that of subdrain material and will remain permeable throughout the active life and post–closure maintenance period of the landfill may be placed adjacent to the liner in this type of system. The liner shall be sloped towards the subdrain(s) to prevent ponding.

(g) Collected leachate shall be system returned to the waste management unit(s) from which it came or discharged in another manner approved by he regional board. Collected leachate may be discharged to a different waste management unit if:

(1) the receiving waste management unit has a leachate collection and removal system, contains wastes which are similar in classification and characteristics to those in the waste management unit(s) from which leachate was extracted, and has at least the same classification under Article 3 of this subchapter as the units from which leachate was extracted; and

(2) the discharge to a different waste management unit is approved by the regional board; and

(3) the discharge of leachate to a different waste management unit shall not exceed the moisture–holding capacity of the receiving unit, and shall comply with Subsection 2520(d) of this subchapter.

NOTE: Authority cited: Section 1058, Water Code. Reference: Sections 13172 and 13360, Water Code.

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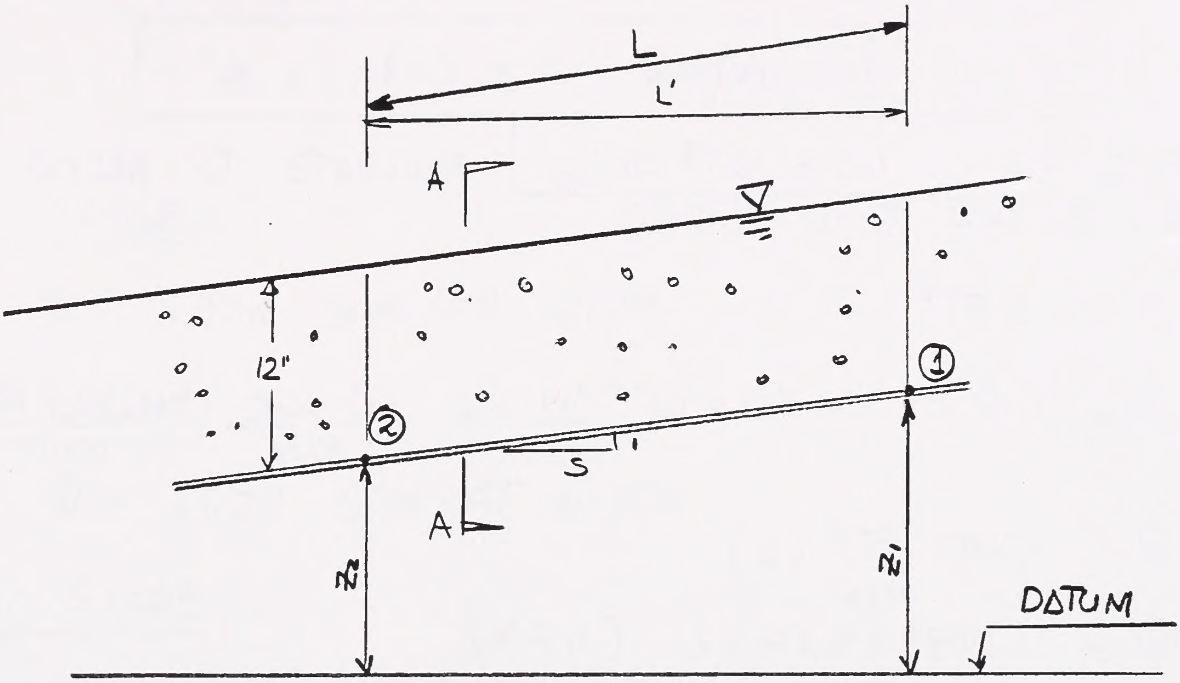
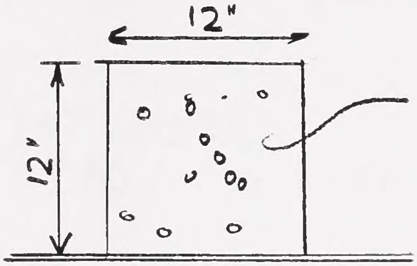


$h_1 = z_1 + p_1$

$h_2 = z_2 + p_2$

$p_2 = p_1 = 62.4 \frac{P}{FT^3} \times \frac{12''}{12} = 62.4\ PSF$

$\Delta h = h_1 - h_2 = z_1 - z_2$



$A = 1\ FT^2$

$Q = A K i$

$L = L'$ FOR SLOPES OF THE ORDER OF 1 TO 2 %

$$i = \frac{h_1 - h_2}{L} = \frac{h_1 - h_2}{L'}$$

$$i = \frac{Z_1 - Z_2}{L'} = \frac{\Delta Z}{L'} =$$ SLOPE OF SUBGRADE

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$$Q = A K i$$

FOR $\boxed{K = 1.0 \times 10^{-2} \text{ cm/sec}}$ EVALUATE Q BASED ON 1, 2 AND 5% SLOPE

$A = 1 \text{ FT}^2$

$$Q = 1.0 \text{ FT}^2 \times 1.0 \times 10^{-2} \frac{\text{cm}}{\text{sec}} \times 60 \frac{\text{sec}}{\text{MIN}} \times \frac{.0328 \text{ FT}}{\text{cm}} \times i$$

$$Q = .0197 \frac{\text{FT}^3}{\text{MIN}} (i)$$

$$Q = .0197 (7.48) i \quad (\text{GPM})$$

$$Q = .1472 i \text{ GPM / FT WIDTH}$$

5% SLOPE

$$Q = .1472 (.05) = .0074 \text{ GPM / FT WIDTH}$$

2% SLOPE

$$Q = .1472 (.02) = .0029 \text{ GPM / FT WIDTH}$$

1% SLOPE

$$Q = .1472 (.01) = .0015 \text{ GPM / FT WIDTH}$$

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$$\boxed{K = 1.0 \times 10^{-1} \text{ cm/sec}}$$

5% SLOPE

Q = .074 GPM / FT WIDTH.

2% SLOPE

Q = .029 GPM / FT WIDTH

1% SLOPE

Q = .015 GPM / FT WIDTH

$$\boxed{K = 1.0 \text{ cm/sec}}$$

5% SLOPE

Q = .74 GPM / FT WIDTH

2% SLOPE

Q = .29 GPM / FT WIDTH

1% SLOPE

Q = .15 GPM / FT WIDTH

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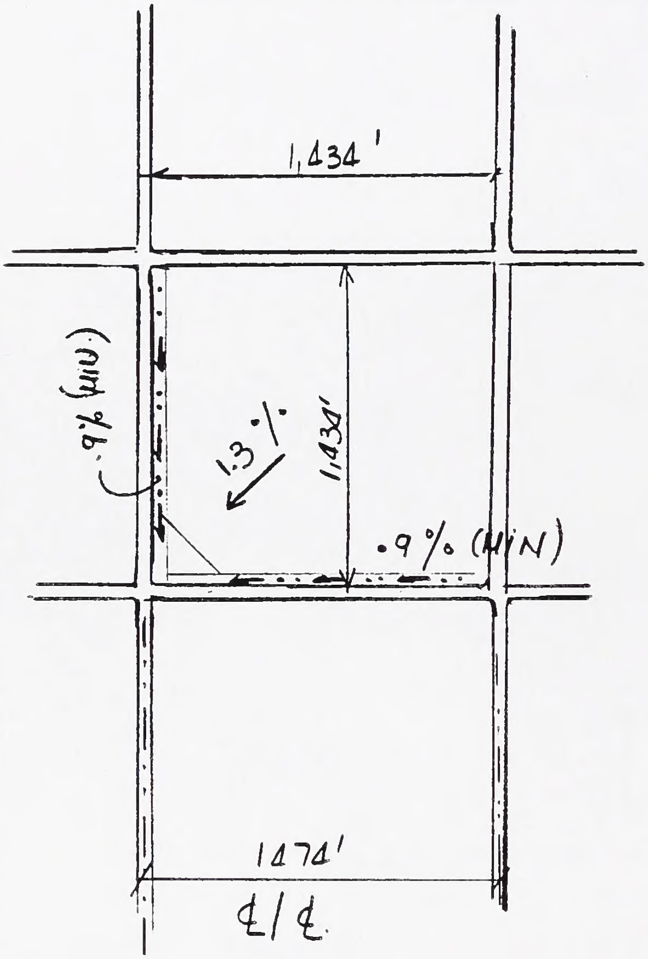
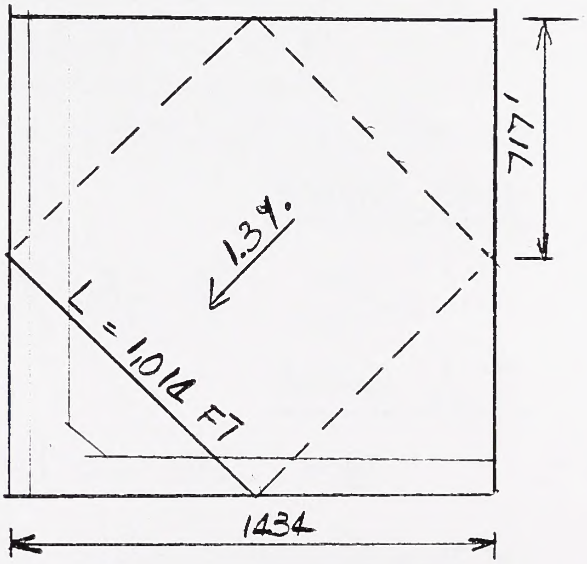
DRAINAGE PATTERN





PLAN VIEW : SEE FIGURE 1 (SHEET 23).

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CAPACITY OF GRAVEL LAYER FOR AN EQUIVALENT WIDTH OF 1,014 FT

$$\boxed{K = 1.0 \times 10^{-2}\ \text{cm/sec}}$$

5% SLOPE

$$Q = .0074\ \frac{\text{GPM}}{\text{FT}} \times 1{,}014\ \text{FT} = 7.50\ \text{GPM}$$

2% SLOPE

$$Q = .0029\ \frac{\text{GPM}}{\text{FT}} \times 1{,}014\ \text{FT} = 2.94\ \text{GPM}$$

1% SLOPE

$$Q = .0015\ \frac{\text{GPM}}{\text{FT}} \times 1{,}014\ \text{FT} = 1.52\ \text{GPM}$$

$$\boxed{K = 1.0 \times 10^{-1}\ \text{cm/sec}}$$

5% SLOPE

$$Q = .074\ \frac{\text{GPM}}{\text{FT}} \times 1{,}014\ \text{FT} = 75.04\ \text{GPM}$$

2% SLOPE

$$Q = .029\ \frac{\text{GPM}}{\text{FT}} \times 1{,}014\ \text{FT} = 29.40\ \text{GPM}$$

1% SLOPE

$$Q = .015\ \text{GPM/FT} \times 1{,}014\ \text{FT} = 15.21\ \text{GPM}$$

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By J. B Date 2/4/93 Subject MESQUITE REGIONAL LANDFIll Sheet No. 9 of 31

Chkd. By EC Date 11/17/93 Proj. No. 92-302

$$\boxed{K = 1.0\ \text{Cm/sec}}$$

5 % SLOPE

$$Q = .74\ \frac{GPM}{FT} \times 1{,}014\ FT = 750.40\ GPM$$

2 % SLOPE

$$Q = .29\ \frac{GPM}{FT} \times 1{,}014\ FT = 294.10\ GPM$$

1 % SLOPE

$$Q = .15\ \frac{GPM}{FT} \times 1{,}014\ FT = 152.10\ GPM$$

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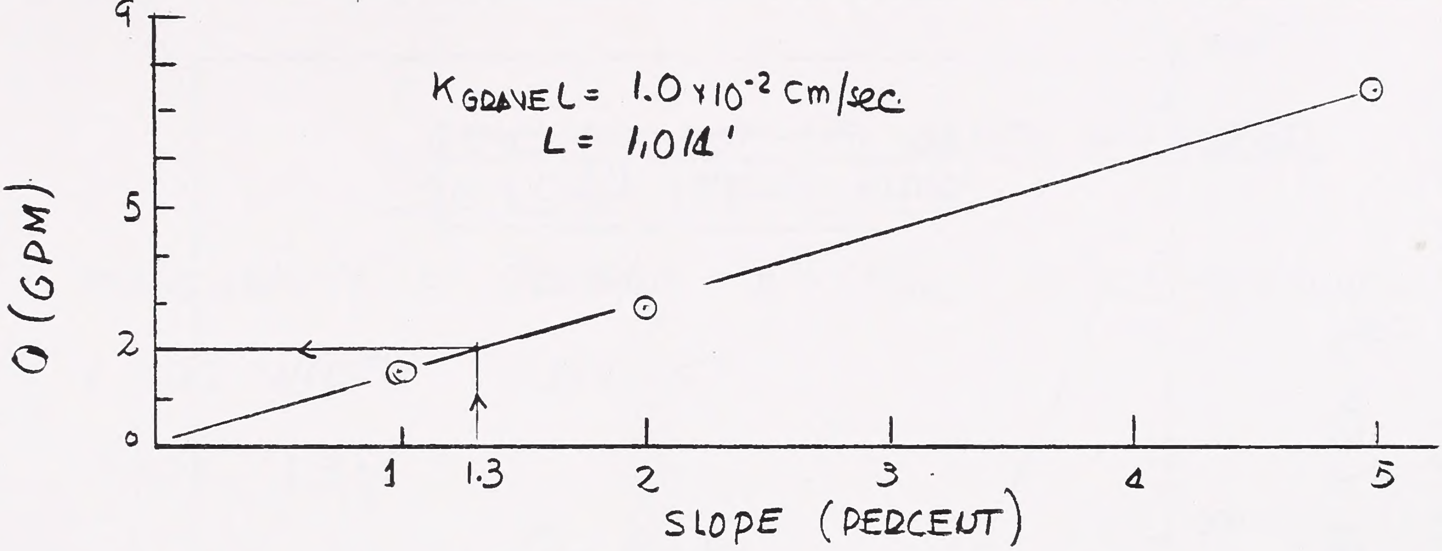
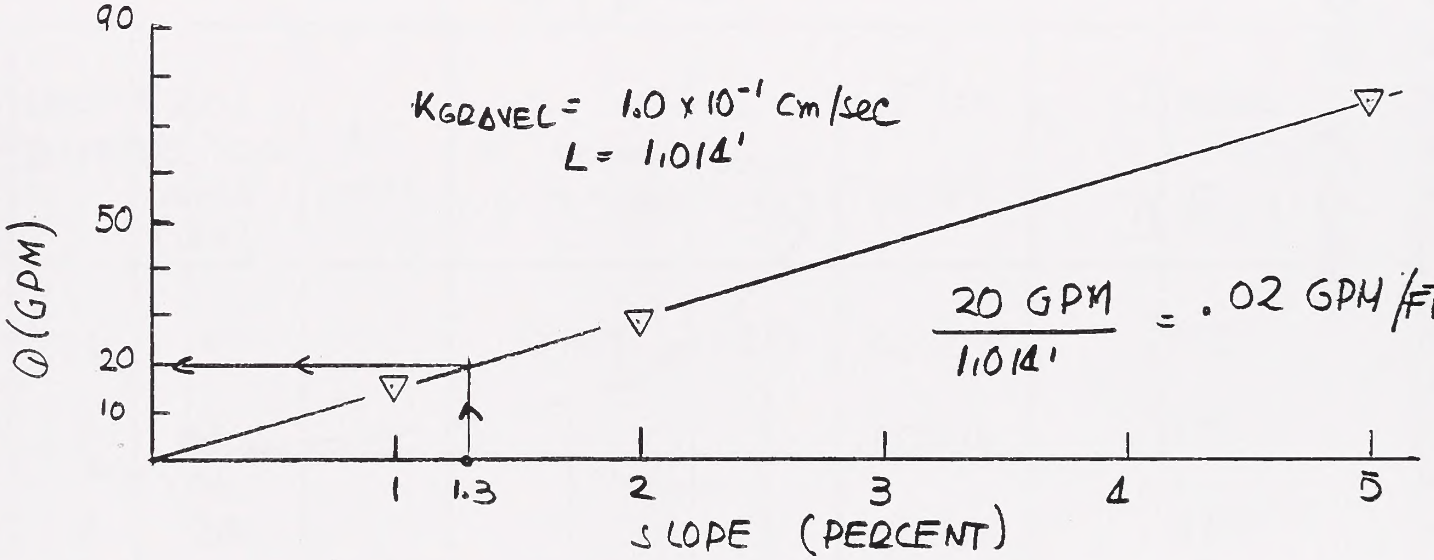
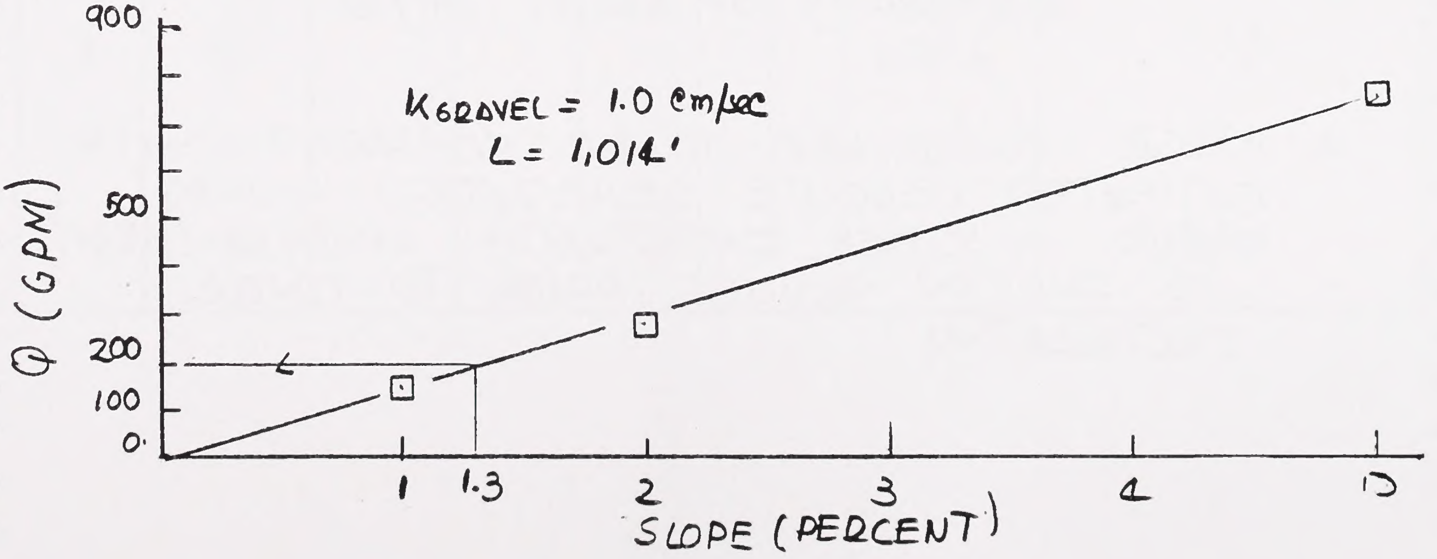
By J. B Date 2/4/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 10 of 31

Chkd. By EC Date 11/17/93 Proj. No. 92-302





$$\frac{20\ \text{GPM}}{1{,}014'} = .02\ \text{GPM/FT}$$



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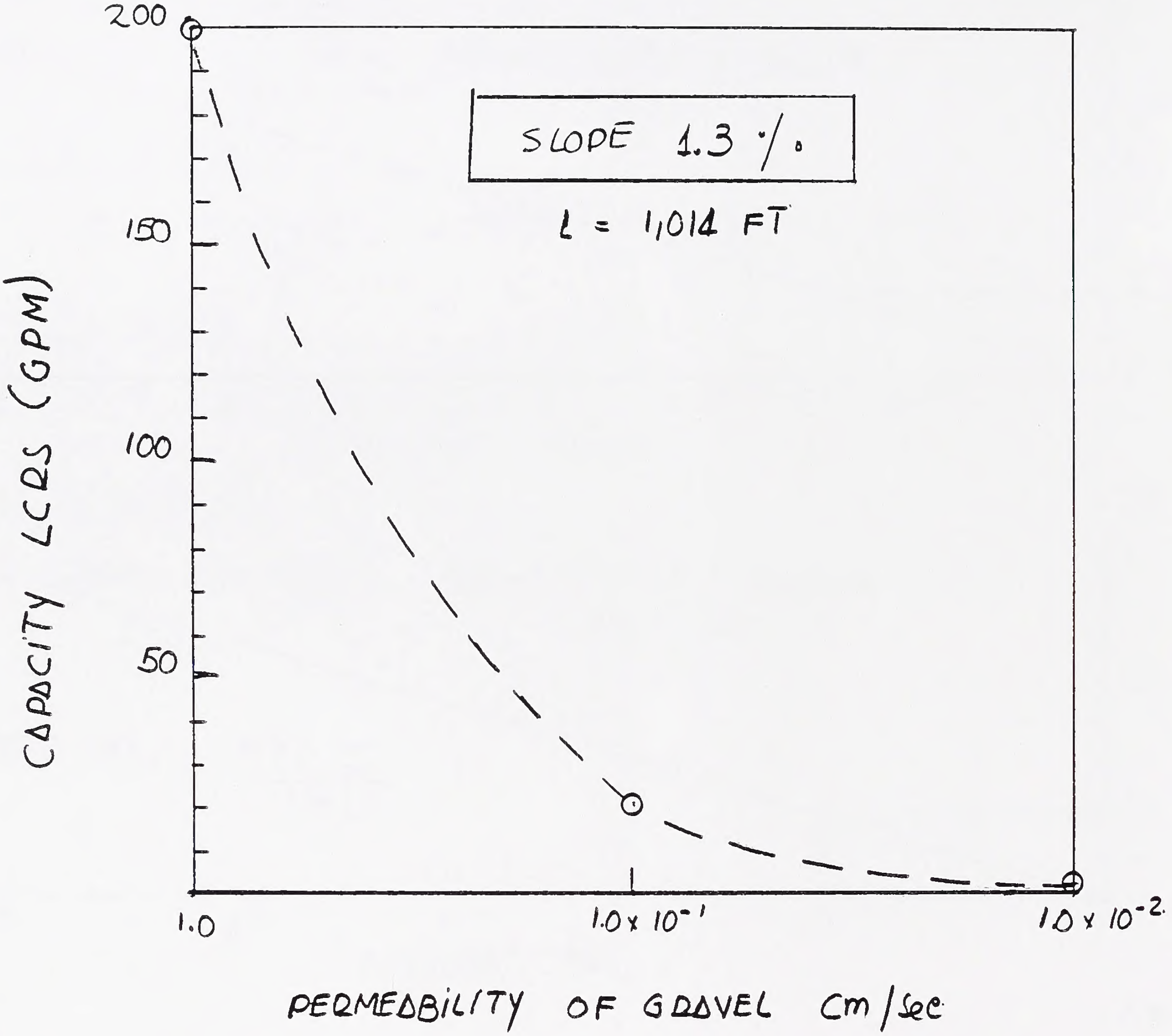
By J. B Date 2/4/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 11 of 31

Chkd. By EC Date 11/17/93 Proj. No. 92-302



=> THESE VALUES ARE TO BE COMPARED WITH ESTIMATED LEACHATE GENERATION VOLUMES BASED ON COVER INFILTRATION ANALYSIS (HELP) AND RUN-ON VOLUMES PRIOR TO COVER INSTALLATION

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By J.B Date 3/19/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 12 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

DEVELOP PLOT OF DEPTH OF WATER ON LCRS VERSUS FLOW -

PERMEABILITY OF GRAVEL: 10^{-2} cm/sec, 10^{-1} $\frac{cm}{sec}$, 10 $\frac{cm}{sec}$

LCRS WIDTH: 1,500 FT

SLOPE: 1.3%

$$Q = A \times K i$$

DEPTH (INCHES)	CROSS SECTIONAL AREA (in^2)	A (FT^2)	K 10^{-2} cm/sec .0197 FT/MIN	i (SLOPE 1.3%)	Q/FT (GPM)	Q TOTAL (L = 1,500') (GPM)
.5	6		.0197	.013	.00008	.120
1	12		↓	↓	.00016	.239
2	24		↓	↓	.00032	.480
4	48		↓	↓	.0006	.958
8	96		↓	↓	.001	1.916
12	144		↓	↓	.002	2.873

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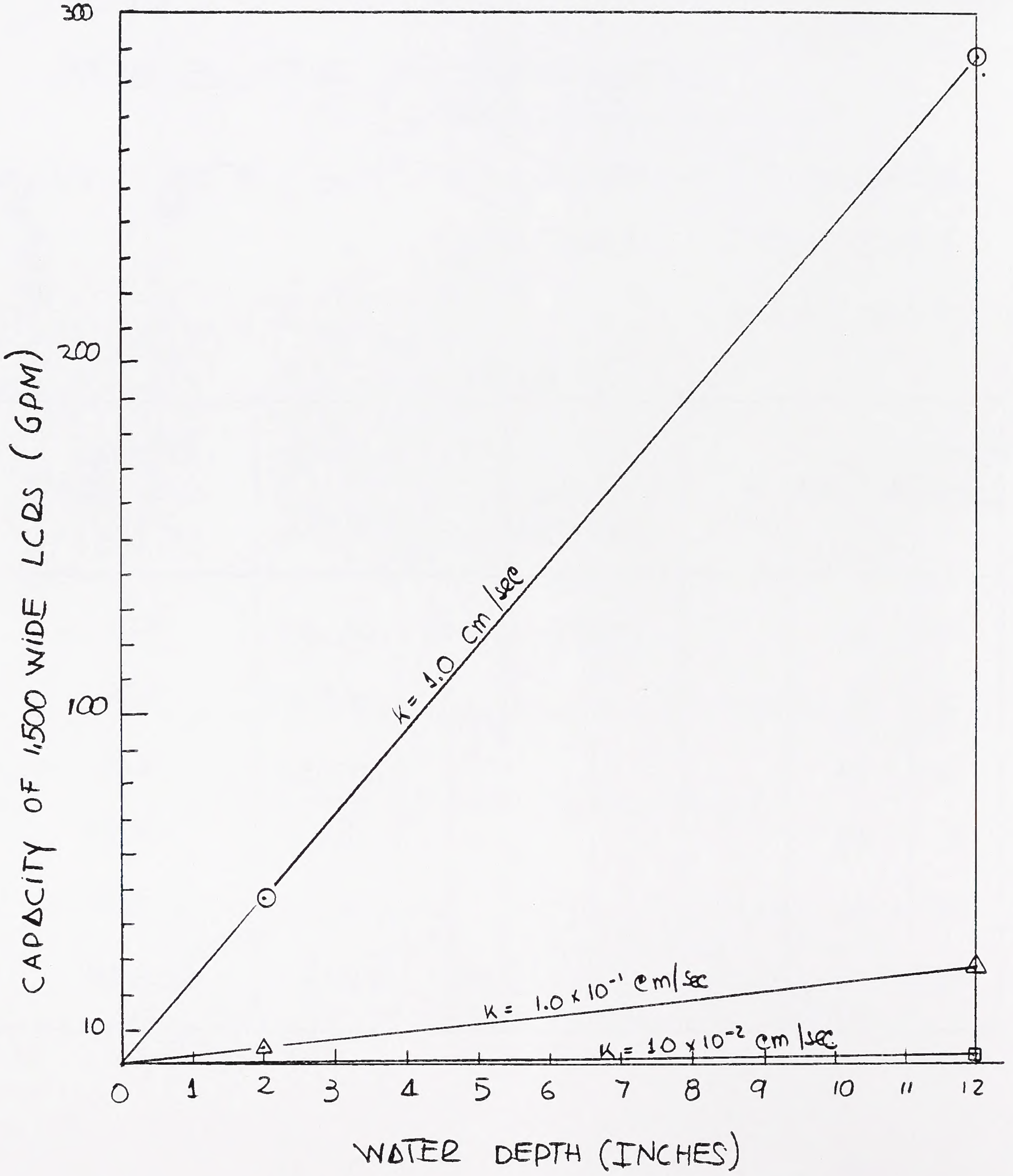
By J.B Date 3/19/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 13 of 31

Chkd. By EC Date 11/17/93 Proj. No. 92-302



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By J. B Date 3/19/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 14 of 31

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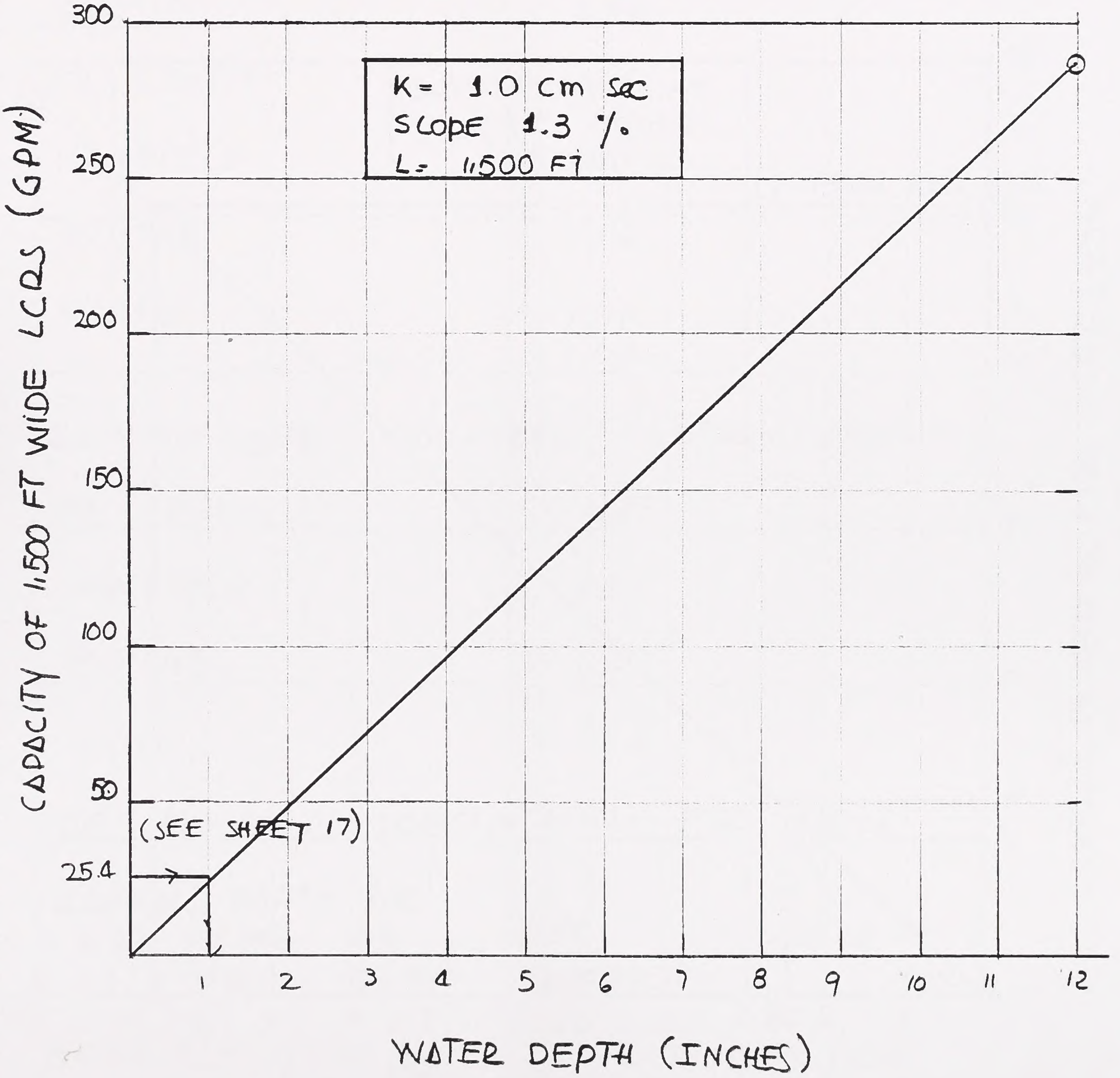

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By J.B Date 3/19/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 15 of 31

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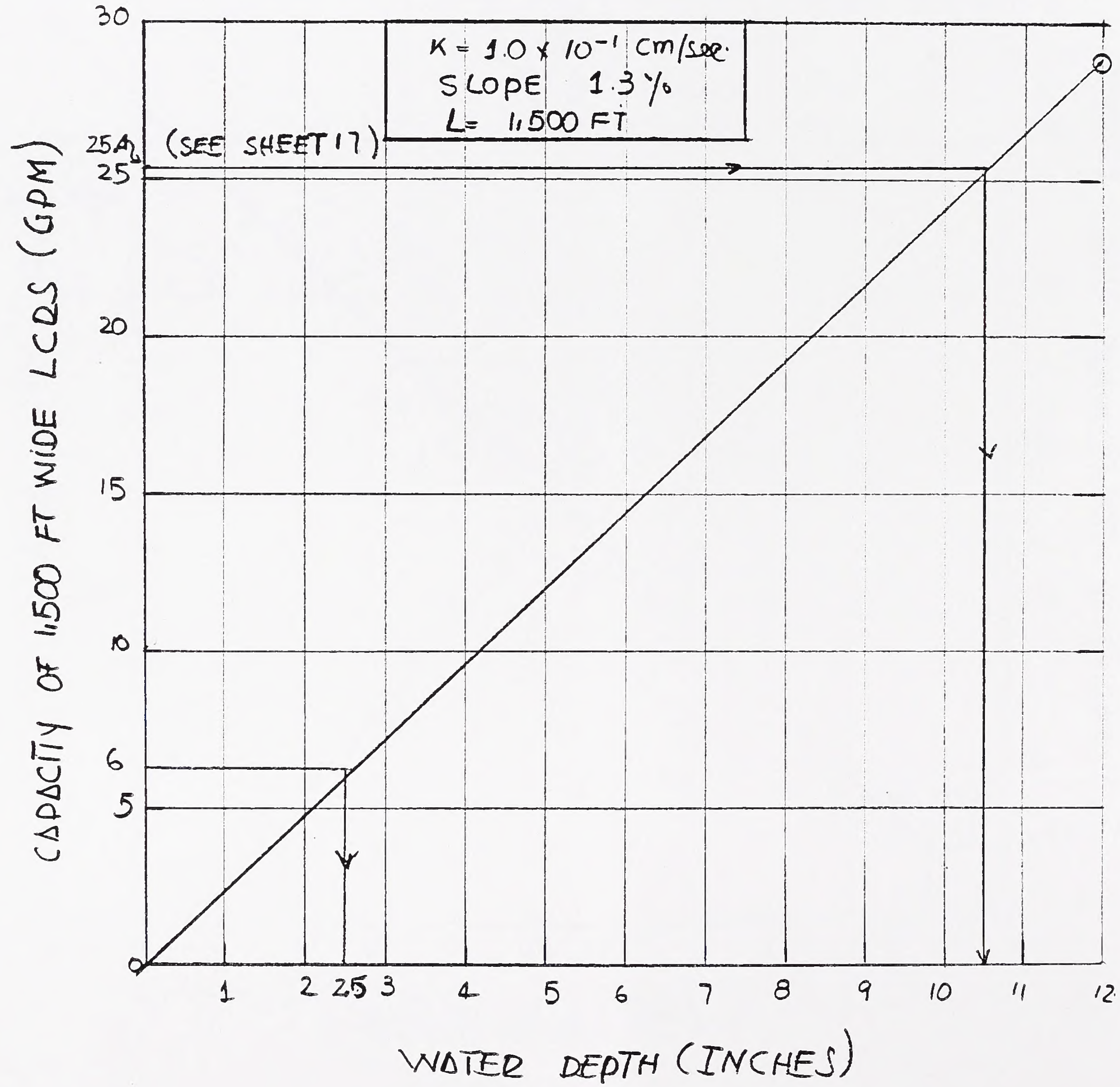

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By J B Date 3/19/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 16 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

RAINFALL DATA

RAINFALL DATA - 25-YEAR RETURN PERIOD

STATION	PRECIPITATION DEPTH (IN) 1 HR.
EL CENTRO	1.05
HAYFIELD	.87
BLYTHE	1.02
YUMA	1.19
MEAN	1.03

RAINFALL DATA 100-YEAR RETURN PERIOD

EL CENTRO	1.28
HAYFIELD	1.19
BLYTHE	1.40
YUMA	1.63

USE 100-YEAR PRECIPITATION FOR YUMA

RAINFALL DEPTH /HR

$$1.63 \frac{\text{INCHES}}{\text{HR}} \times \frac{\text{HR}}{60\ \text{MIN}} \times \frac{1\ \text{FT}}{12\ \text{INCHES}} = .0023 \frac{\text{FT}}{\text{MIN}}$$

$$.0023 \frac{\text{FT}^3}{\text{MIN}} \times 7.48 \frac{\text{GAll}}{\text{FT}^3} = .0169\ \text{GPM}/\text{SF}$$

(FLOW THROUGH 1 SQ FT HORIZONTAL PLANE)

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By J.B Date 3/19/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 17 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

FLOW THROUGH 1,500 FT WIDE SECTION

$$.0169 \frac{GPM}{FT^2} \times 1{,}500\ FT = \underline{\underline{25.40}}\ GPM/FT$$

IN THE DIRECTION OF FLOW

=> FROM SHEET 15, FOR $K = 1.0 \times 10^{-1}$ cm/sec THE WATER DEPTH EQUALS 10 ½ INCHES.

=> LEACHATE COLLECTION AND REMOVAL SYSTEM WITH PERMEABILITY OF GRAVEL $K \geq 1.0 \times 10^{-1}$ cm/sec CAN HANDLE THE 100-YEAR STORM FLOW WITHOUT BUILDING UP MOR THAN 12 INCHES OF HEAD OVER THE LINER

TITLE 23, SUBCHAPTER 15, SECTION 2543 (b)

"LCRS SHALL BE DESIGNED, CONSTRUCTED, MAINTAINED AND OPERATED TO COLLECT AND REMOVE TWICE THE MAXIMUM ANTICIPATED DAILY VOLUME OF LEACHATE FROM THE WASTE MANAGEMENT UNIT

ASSUME 1 HR PRECIPITATION FOR 25-YEAR RETURN PERIOD

MEAN PRECIPITATION DEPTH (FROM SHEET 16) $= 1.03 \frac{INCH}{HR}$

$$= 1.03 \frac{INCH}{HR} \times \frac{HR}{60\ MIN} \times \frac{1\ FT}{12\ INCHES}$$

$$= .0014\ FT/MIN$$

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By J. B Date 4/9/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 18 of 31

Chkd. By EC Date 11/17/93 Proj. No. 92-302

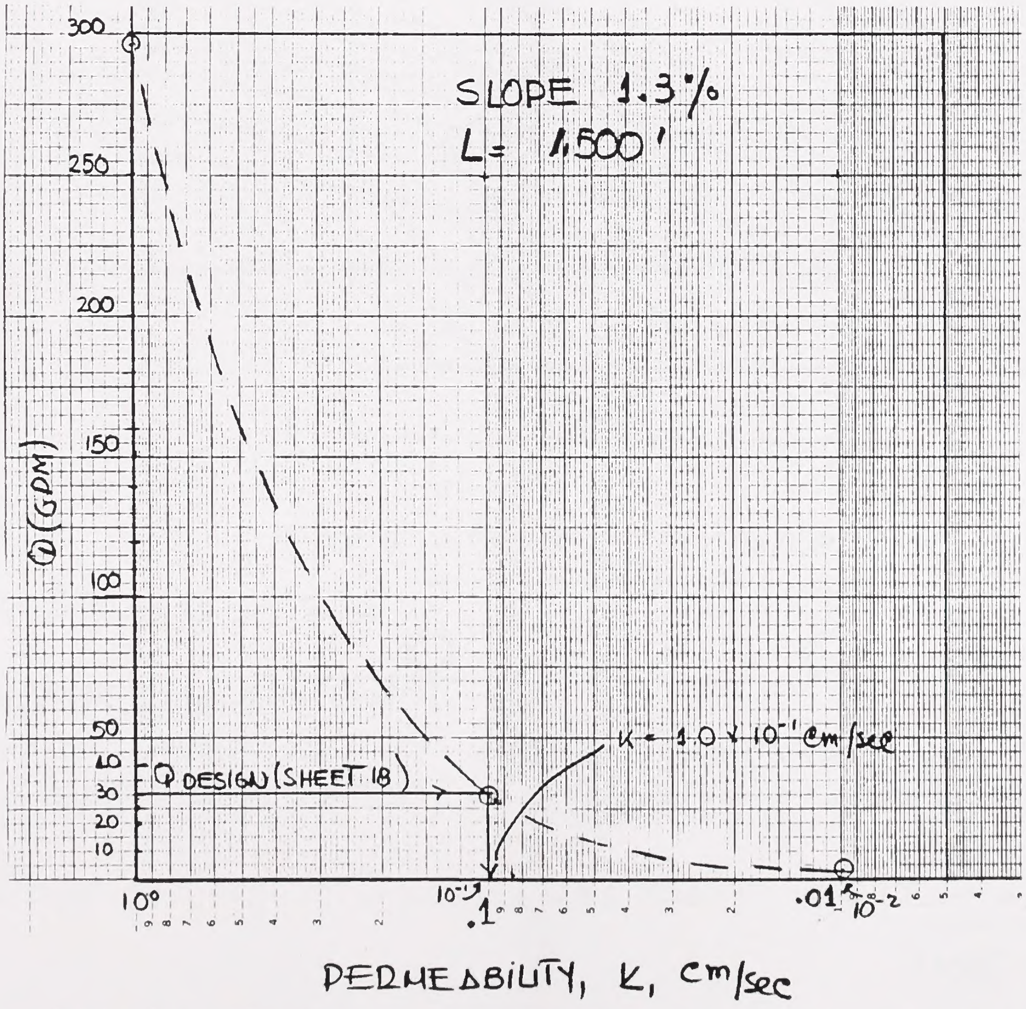
$$.0014\ \frac{FT}{MIN} \times 1\ FT \times 1\ FT = .0014\ \frac{FT^3}{MIN}$$

$$.0014\ \frac{FT^3}{MIN} \times 7.48\ \frac{GALL}{FT^3} = .0107\ GPM$$

FLOW THROUGH A 1,500 FT WIDE STRIP PERPENDICULAR TO THE DIRECTION OF FLOW

$$Q = .0107\ GPM \times 1{,}500 = 16.05\ GPM$$

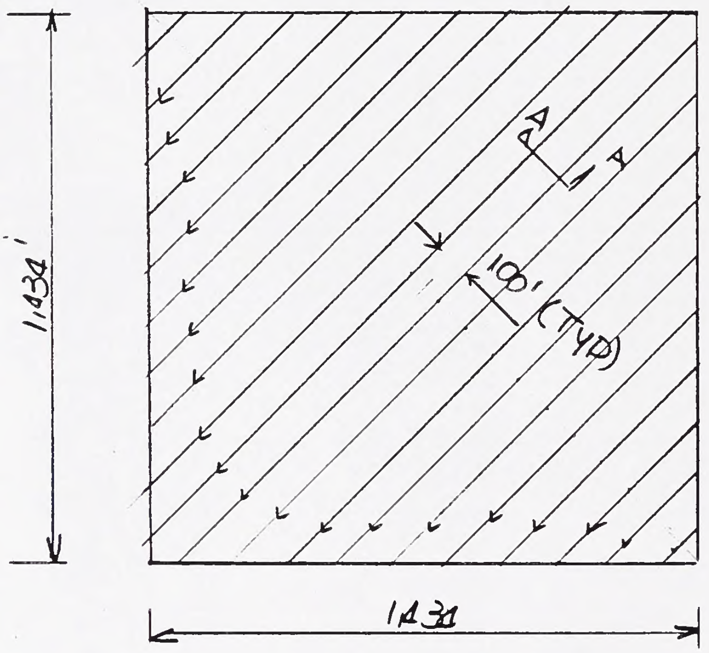
$$Q\ DESIGN = 2\ (16.05) = 32.10\ GPM$$

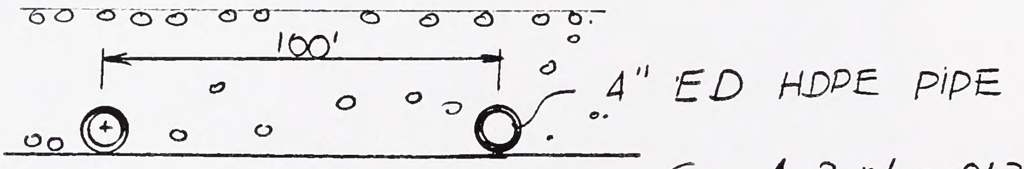


ENVIRONMENTAL SOLUTIONS, INC.

By J.B Date 4/9/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 19 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

THIS VALUE MAY NOT BE OBTAINED WITH GRAVEL AT HIGH CONFINING STRESSES (314 K.S.F.) ⇒ USE PERFORATED PIPES WITHIN THE GRAVEL LAYER TO INCREASE THE CAPACITY OF THE SYSTEM SIGNIFICANTLY AND BE ABLE TO SPECIFY LESS RESTRICTIVE PERMEABILITY VALUES FOR THE GRAVEL





S= 1.3 % = .013

SECTION A A

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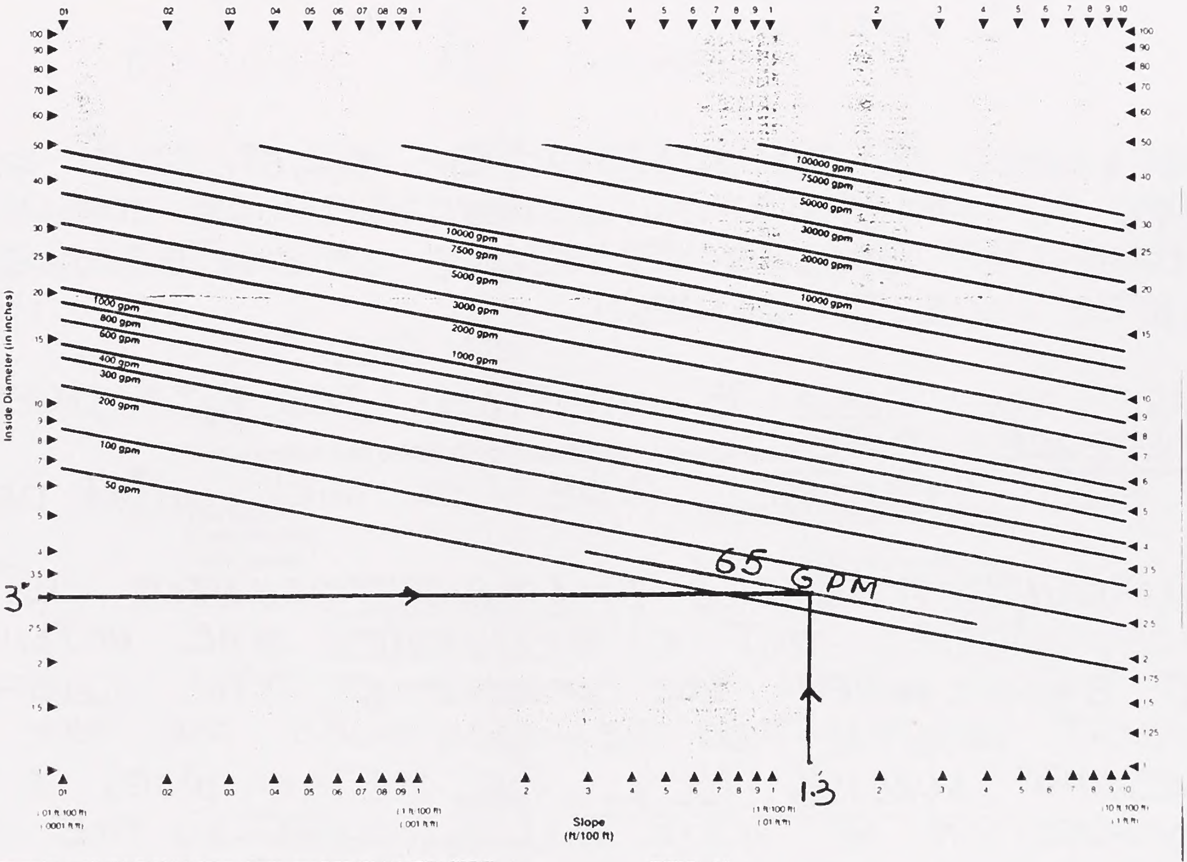
By J.B Date 4/9/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 20 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

EVALUATE CAPACITY OF 3" ID HDPE PIPE.

TRY DRISCOPIPE DESIGN CHART

Chart 7
Inside Diameter vs. Flow Rate at a Given Slope
Gravity Full Flow: Water



Q PIPE = 65 GPM
PIPES ARE 100 FT APART
Q PIPE PER FOOT = $\frac{65 \text{ GPM}}{100}$ = .65 GPM

Q PIPE PER FOOT + Q GRAVEL PER FOOT = $.65 + \underbrace{.02}_{\text{SHEET 10}} = .67$ GPM

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By J.B Date 4/9/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 21 of 31

Chkd. By EC Date 11/17/93 Proj. No. 92-302.

CAPACITY OF LCRS FOR L = 1,500:

.67 GPM x 1,500 = 1,005 GPM

Q_{DESIGN} (SHEET 18) = 32.10 GPM

$$\frac{\text{LCRS CAPACITY}}{Q_{\text{DESIGN}}} = \frac{1{,}005}{32.10} = \frac{31}{1}$$

⇒ ADDING 3' ID HDPE PIPES 100 FT APART AS SHOW IN SHEET 19 WILL PROVIDE MORE THAN ADEQUATE CAPACITY TO HANDLE LEACHATE GENERATION RATES DUE TO RAINFALL

USE PIPES ABLE TO WITHSTAND 34.4 K.SF PRESSURE

PREFERRED OPTION:

ADS CORRUGATED PIPE - OR THICK walled DRISCO PIPE

INFORMATION PROVIDED BY ADVANCED DRAINAGE SYSTEM INC (ADS) INDICATES THAT 6" ADS SLOTTED PIPE INSTALLED AT BKK LANDFILL ARE OPERABLE AT TOTAL LANDFILL HEIGHT GREATER THAN THE VALUE USED FOR THE MESQUITE ANALYSIS (450'). FOR THE BKK PIPES A PIPE DEFLECTION OF 10.5% WAS CALCULATED BY THE FINITE ELEMENT CANDE LEVEL 2 COMPUTER PROGRAM FOR A MAXIMUM LANDFILL HEIGHT OF 600 FEET.

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By J.B Date 4/9/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 22 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

PIPING SYSTEM: SEE FIGURES 1 AND 2

CAPACITY OF THE MAIN COLLECTORS LOCATED ON THE WESTERN AND SOUTHERN BOUNDARIES

MINIMUM SLOPE .9 %

DIAMETER 12 INCHES

THESE PIPES ARE NOT SUBJECTED TO THE MAXIMUM LOAD DUE TO THE WEIGHT OF THE WASTE BECAUSE THEY ARE LOCATED AT THE EDGES OF THE WASTE PRISM.

USE SDR 17

Values of E′
Based on Soil Type (ASTM D2321) and Degree of Compaction

Soil Type of Initial Backfill Embedment Material	Description	E′ (psi) for Degree of Compaction (Proctor Density, %)			
		Loose	Slight (70-85%)	Moderate (85-95%)	High (95%)
I	Manufactured angular, granular materials (crushed stone or rock, broken coral, cinders, etc.)	1,000	3,000	3,000	3,000
II	Coarse grained soils with little or no fines	N.R.	1,000	2,000	3,000
III	Coarse grained soils with fines	N.R.	N.R.	1,000	2,000
IV	Fine-grained soils	N.R.	N.R.	N.R.	N.R.
V	Organic soils (peat, muck, clay, etc.)	N.R.	N.R.	N.R.	N.R.

N.R. = Not Recommended for use by ASTM D2321 for pipe wall support

Chart 24

SDR	Maximum Burial Depth, ft. in dry soil of 100 lbs/cu. ft.			Maximum External Pressure psi			Maximum Deflection, % after installation		
	Soil Modulus, psi*			Soil Modulus, psi*			Soil Modulus, psi*		
	1000	2000	3000	1000	2000	3000	1000	2000	3000
32.5	25	32	37	17	22	26	1.7	0.9	0.6
26	33	45	52	23	31	36	2.3	1.2	0.8
21	46	61	71	32	42	49	3.2	1.6	1.1
19	52	69	81	36	48	56	3.6	1.8	1.2
17	61	121	181	42	84	126	4.2	2.1	1.4
15.5	56	112	168	39	78	117	3.9	2.0	1.3
13.5	49	98	147	34	68	102	3.4	1.7	1.1
11	39	78	117	27	54	81	2.7	1.4	0.9
9.3	33	68	101	23	47	70	2.3	1.2	0.8
8.3	30	61	89	21	42	62	2.1	1.1	0.7
7.3	26	52	79	18	36	55	1.8	0.9	0.6

*assumes no external loads

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SCALE 1" = 1,000'

SHEET No 23 OF 31

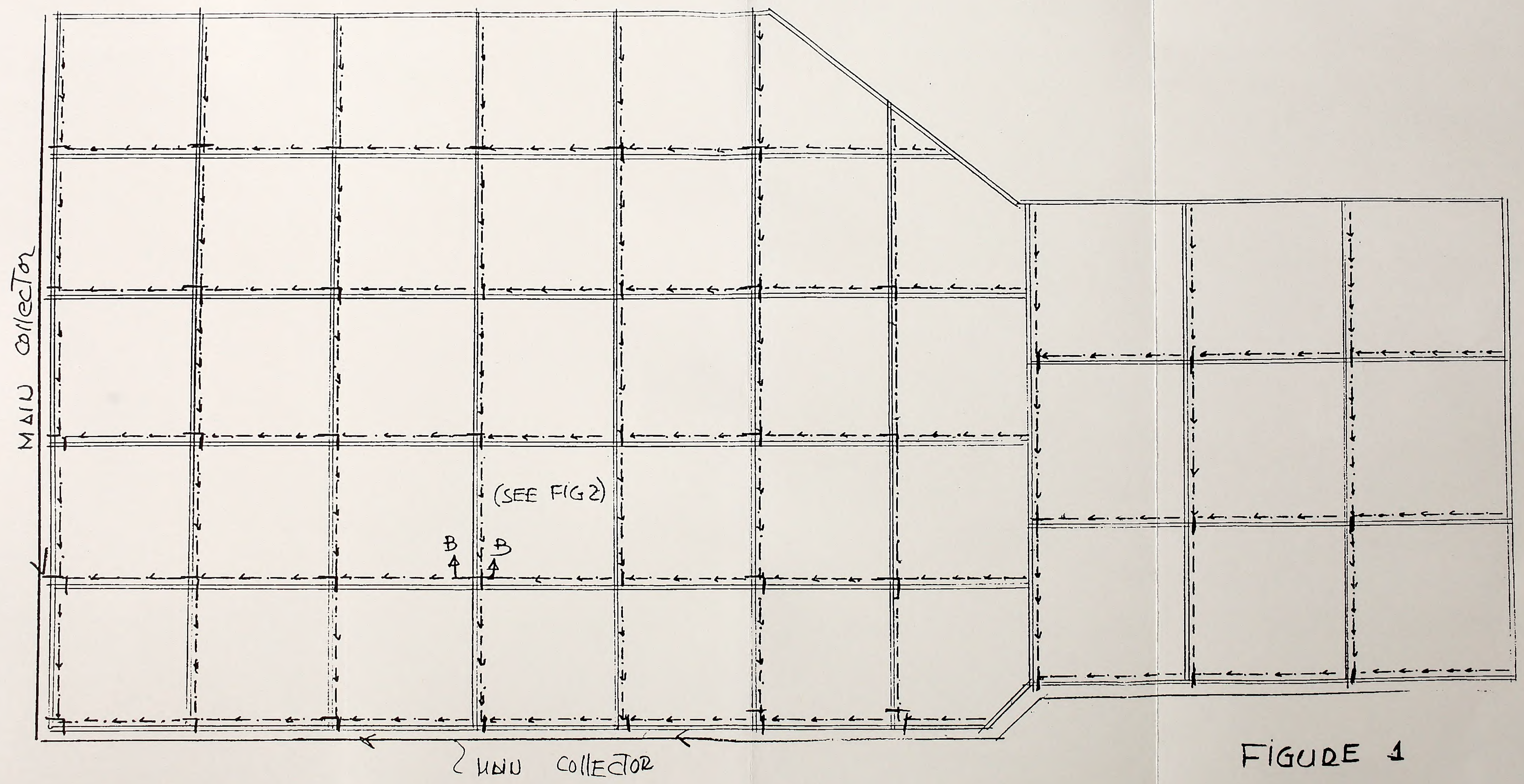
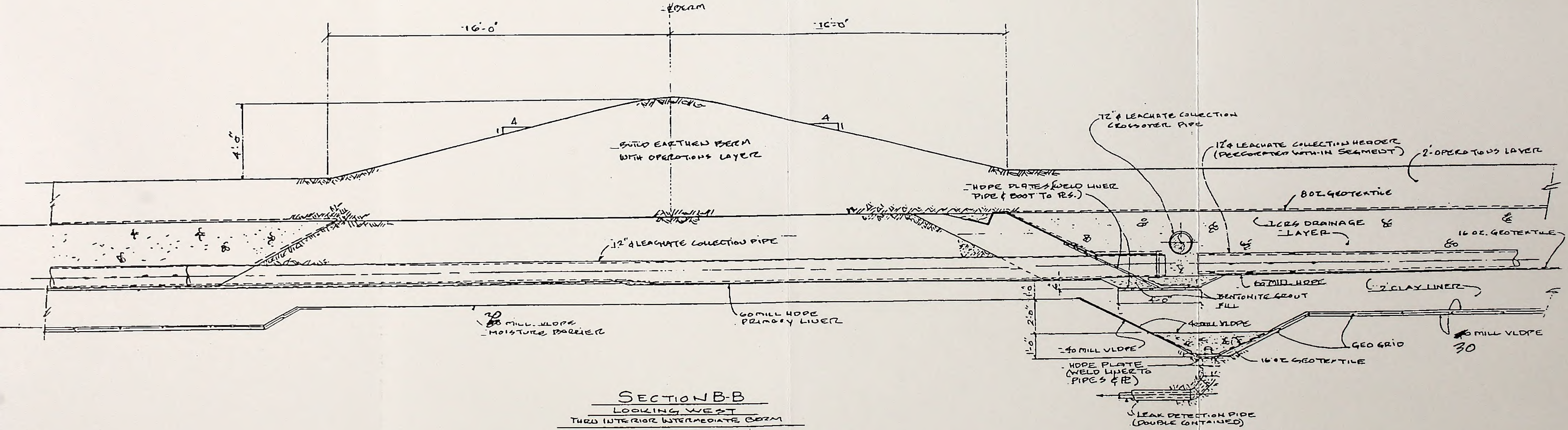


FIGURE 1


℄ BERM
16'-0"
16'-0"
4'-0"
4
1
4
1
BUILD EARTHEN BERM WITH OPERATIONS LAYER
12" ⌀ LEACHATE COLLECTION PIPE
30 MILL VLDPE MOISTURE BARRIER
60 MILL HDPE PRIMARY LINER
12" ⌀ LEACHATE COLLECTION CROSSOVER PIPE
12" ⌀ LEACHATE COLLECTION HEADER (PERFORATED WITH-IN SEGMENT)
2' OPERATIONS LAYER
HDPE PLATES (WELD LINER PIPE & BOOT TO PLS.)
8 OZ. GEOTEXTILE
1' CRS DRAINAGE LAYER
16 OZ. GEOTEXTILE
60 MIL HDPE
BENTONITE GROUT FILL
4'-0"
2' CLAY LINER
1'-0"
2'-0"
1'-0"
40 MILL VLDPE
40 MILL VLDPE
GEO GRID
30 MILL VLDPE
16 OZ GEOTEXTILE
HDPE PLATE (WELD LINER TO PIPES & PL)
LEAK DETECTION PIPE (DOUBLE CONTAINED)

SECTION B-B
LOOKING WEST
THRU INTERIOR INTERMEDIATE BERM
@ 2'-0" CLAY LINER SECTION

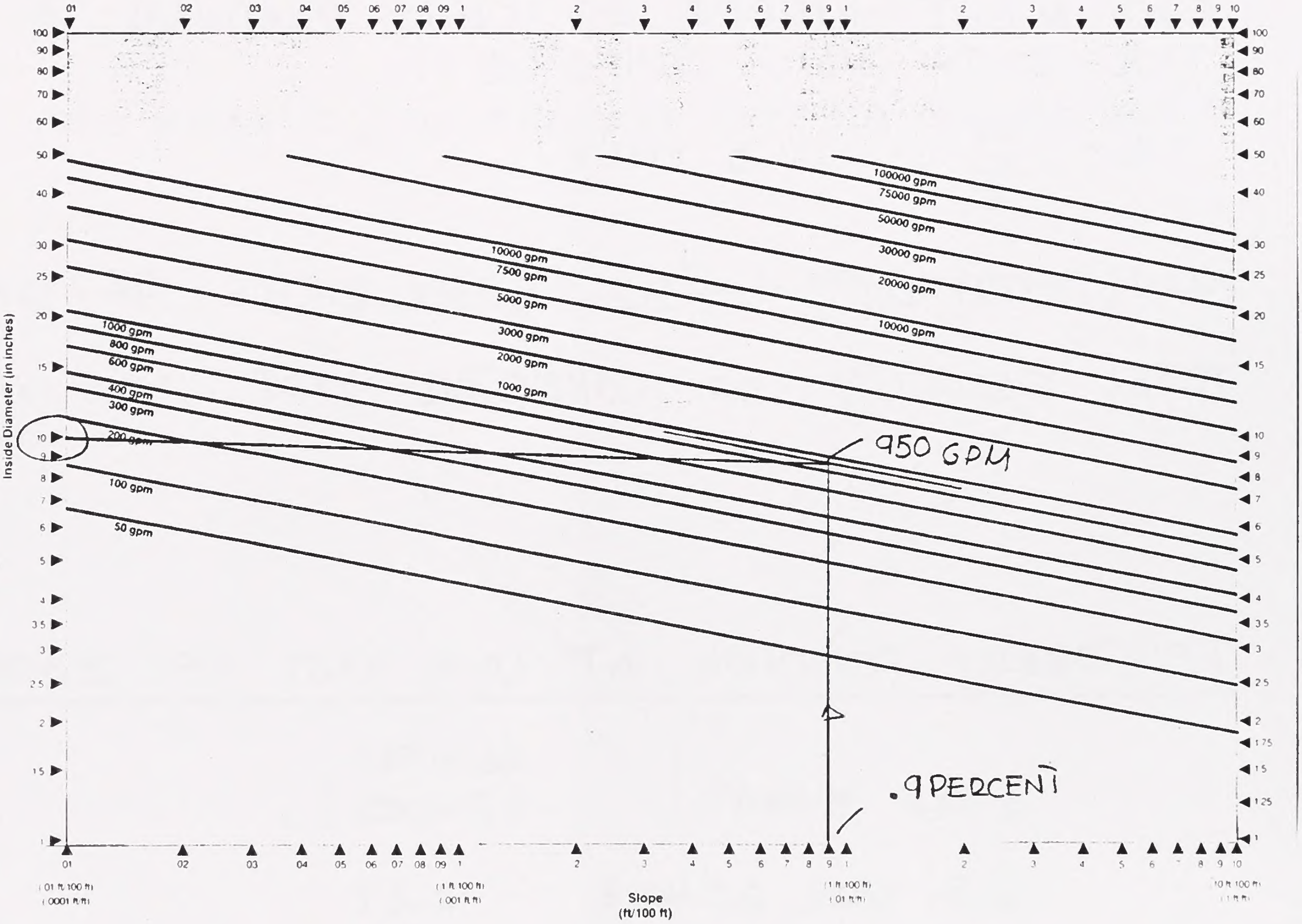
℄ 1905 1" PL
1660 ½ PL

FIGURE 2

By J.B Date 4/10/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 25 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

SLOPE .009 , 10" ID

Chart 7
Inside Diameter vs. Flow Rate at a Given Slope
Gravity Full Flow: Water



CAPACITY 950 GPM

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By J.B Date 4/10/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 26 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

① DESIGN DUE TO RAINFALL 32.10 GPM

No OF CELLS : 43, (SEE SHEET 23, FIGURE 1)

EQUIVALENT NUMBER OF CELLS DRAINING TO THE SOUTH MAIN COLLECTOR:

$$16 + \frac{27}{2} = 29.5 \text{ CELLS}$$

MAX FLOW RATE = 32.1 GPM x 29.5 = 947 GPM

TOTAL CAPACITY OF COLLECTOR PIPE: 950 GPM
OK.

TEMPORARY PONDING AT LOW END OF SEGMENT

STORM EVENT	RAINFALL (INCHES)
25-YEAR, 24-HOUR	2.22
100-YEAR, 24-HOUR	3.0

AREA OF SEGMENT : 1,434 FT x 1,434 FT = 2,056,356 FT²

$$V_{25} = \frac{2.22 \text{ INCHES}}{12} \times 2,056,356 \text{ FT}^2 = 380,426 \text{ FT}^3$$

$$V_{25} = 380,426 \times 7.48 = 2,800,000 \text{ GALLONS}$$

$$V_{100} = \frac{3.0 \text{ INCHES}}{12} \times 2,056,356 \text{ FT}^2 = 514,089 \text{ FT}^3$$

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By M.V. Date 6-11-93 Subject MESQUITE LANDFILL Sheet No. 27 of 31

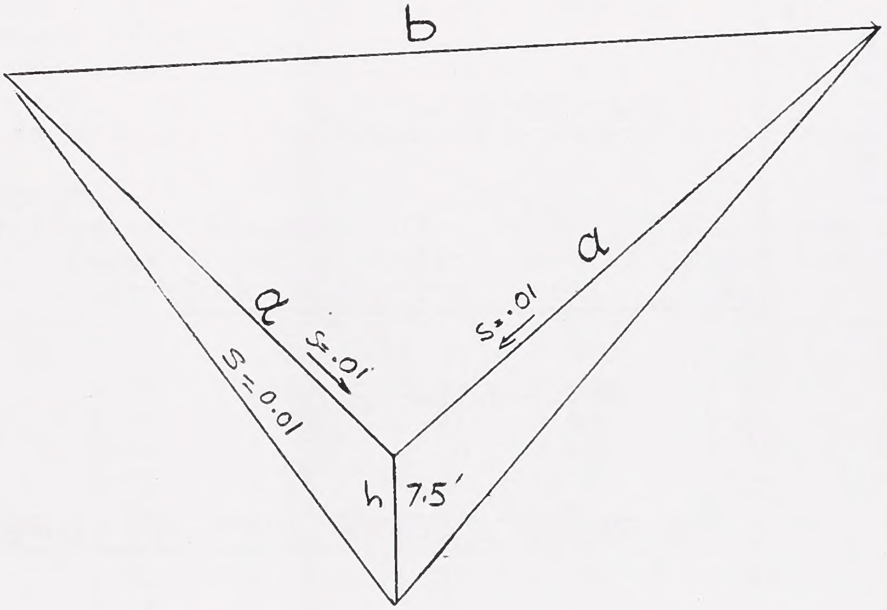
Chkd. By J.B Date 11-12-93 VOLUME OF BASIN NORTH OF PHASE II Proj. No. 92-302

V_{100} = 514,089 FT^3 × 7.48 = 3,800,000 gall.

ALLOWABLE PONDING HEIGHT = 7.5 FT. = 75 PERCENT OF STABILITY BERM HEIGHT. S = 0.01

$a = \frac{7.5}{0.01} = 750$ FT.

THIS WEDGE IS $\frac{1}{4}$ OF A SQUARE PYRAMID, THEREFORE. $V = \frac{a^2 h}{6}$



a = 750 FT.

h = 7.5 FT.

$V = \frac{a^2 h}{6} = \frac{(750)^2 (7.5)}{6} = 703,125 \text{ Ft.}^3$

V = 7.48 × 703,125 = 5,260,000 GALLONS

V = AVAILABLE STORAGE CAPACITY.

PERFORMANCE CURVE FOR 12" HDPE PIPE

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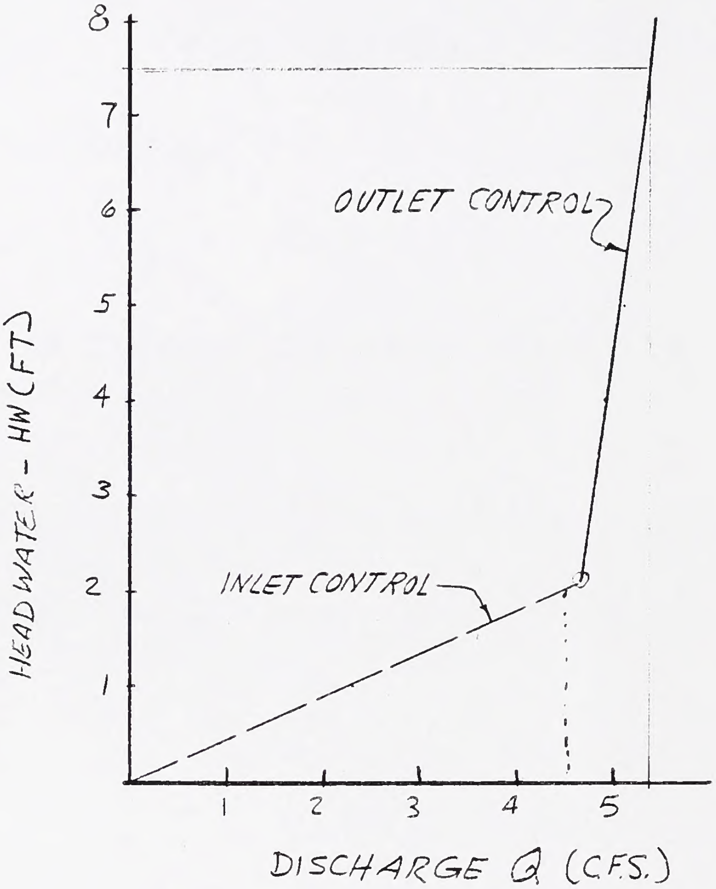
By M.V. Date 6-11-93 Subject MESQUITE LANDFILL Sheet No. 28 of 31
Chkd. By J.B Date 11-12-93 Proj. No. 92-302



PERFORMANCE CURVE FOR 12" HDPE

SHT. 29 OF 31

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                    PIPE CULVERT ANALYSIS
            COMPUTATION OF CULVERT PERFORMANCE CURVE

                        June 11, 1993
                  MESQUITE REGIONAL LANDFILL
                 PERFORMANCE CURVE FOR 12" PIPE

===================================================================

PROGRAM INPUT DATA:
DESCRIPTION                                                   VALUE
-------------------------------------------------------------------
Culvert Diameter (feet).................................     1.00
FHWA Chart Number (1,2 or 3)............................     1
Scale Number on Chart (Type of Culvert Entrance)........     1
Manning's Roughness Coefficient (n-value)...............     0.0100
Entrance Loss Coefficient of Culvert Opening............     0.20
Culvert Length (feet)...................................  1700.0
Culvert Slope (feet per foot)...........................     0.0100

===================================================================

PROGRAM RESULTS:
    Flow Tailwater  Headwater (ft) Normal Critical Depth at   Outlet
    Rate     Depth Inlet    Outlet  Depth    Depth   Outlet Velocity
   (cfs)      (ft) Control Control   (ft)     (ft)     (ft)    (fps)
-------------------------------------------------------------------
     2.3      0.00    1.02  -11.85   0.50     0.65     0.50     5.90
     3.6      0.00    1.50   -5.61   0.66     0.81     0.66     6.53
     4.5      0.00    2.00    0.81   0.80     0.89     0.80     6.73
     4.7      0.00    2.10    2.10   0.83     0.90     0.90     6.33
     4.8      0.00    2.18    3.04   0.87     0.91     0.91     6.45
     4.9      0.00    2.25    4.01   0.92     0.91     0.91     6.58
     5.1      0.00    2.33    4.99   1.00     0.92     0.92     6.71
     5.2      0.00    2.41    6.00   1.00     0.93     0.93     6.84
     5.3      0.00    2.49    7.04   1.00     0.93     0.93     6.97
     5.4      0.00    2.57    8.00   1.00     0.94     0.94     7.09
     5.6      0.00    2.72   10.00   1.00     0.94     0.94     7.34
     5.8      0.00    2.80   11.03   1.00     0.95     0.95     7.47
     5.8      0.00    2.88   11.98   1.00     0.95     0.95     7.59

===================================================================
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By M.V. **Date** 11-12-93 **Subject** MESQUITE LANDFILL **Sheet No.** 30 **of** 31

Chkd. By J.B **Date** 11-12-93 DURATION OF DISCHARGE CALCS. **Proj. No.** 92-307

FROM CULVERT ANLYSIS FOR 12 INCH HDPE PIPE, CONSERVATIVELY

USE DISCHARGE OF 4.5 C.F.S..

RAINFALL VOLUME FOR 25-YEAR 24-HOUR STORM = 380,426 Ft^3 (SHEET 26)

DURATION OF DISCHARGE FOR 25-YEAR 24-HR STORM $= \dfrac{380\,426\ Ft^3}{4.5\ \frac{Ft^3}{SEC}} \Big| \dfrac{1\ HR}{3600\ SEC} = 24$ HRS

RAINFALL VOLUME FOR 100-YEAR 24-HOUR STORM = 514,089 Ft^3 (SHEET 26)

DURATION OF DISCHARGE FOR 100-YR 24-HR STORM $= \dfrac{514{,}089\ FT^3}{4.5\ \frac{Ft^3}{SEC}} \Big| \dfrac{1\ HR}{3600\ SEC} = \underline{32\ HRS}$

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By J.B Date 11/12/93 Subject MESQUITE REGIONAL LANDFILL Sheet No. 31 of 31
Chkd. By EC Date 11/17/93 Proj. No. 92-302

CONCLUSIONS

- THE LCRS CAPACITY USING 12 INCHES OF 10^{-1} cm/sec GRAVEL AND 4 INCH PERFORATED PIPES AT 100-FOOT CENTERS IS ABOUT .67 GPM PER FOOT OF WIDTH, OR CONSERVATELY 1,000 GPM FOR AN ENTIRE SEGMENT AREA (USING L = 1500 FT) PERPENDICULAR TO THE DIRECTION OF FLOW.

- THE CAPACITY OF THE MAIN COLLECTION AND DISCHARGE PIPES IS ABOUT 950 GPM

- THE CAPACITY OF THE 4 INCH PERFORATED PIPE WITHIN THE GRAVEL IS 65 GPM/PIPE

- THE CAPACITY OF 12 INCHES OF $K = 1.0 \times 10^{-1}$ cm/sec PER FOOT OF WIDTH IS .02 GPM.

- TEMPORARY PONDING VOLUMES AT LOW END OF LANDFILL SEGMENT ARE AS FOLLOWS

STORM EVENT	RAINFALL (INCHES)	VOLUME OF WATER (FT^3)	VOLUME OF WATER (GALLONS)
25-YEAR, 24-HOUR	2.22	380,426	2,800,000
100-YEAR;	3.00	514,089	3,800,000

- THE AVAILABLE STORAGE CAPACITY FOR A MAXIMUM ALLOWABLE STABILITY BERM HEIGHT OF 7.5 FEET IS 5,260,000 GALLONS

- THE CAPACITY OF THE LCRS SYSTEM IS VERY LARGE IN COMPARISON WITH ANY SMALL AMOUNT OF LEACHATE THAT MAY OCCUR DUE TO HIGHER MOISTURE CONTENT IN PORTIONS OF THE WASTE

Recyclable and made from recycled paper

APPENDIX I

GW-1 PUMPING TEST RESULTS

APPENDIX I

PUMPING TEST
MONITORING WELL GW-1

1.0 INTRODUCTION

1. A constant rate pumping test was performed on the Monitoring Well GW-1 to better define the hydraulic parameters of the Bear Canyon Conglomerate. The monitoring well is screened within the conglomerate through an area suspected of containing fractures.

2.0 BACKGROUND

1. Monitoring Well GW-1 is located south of the planned layout of the Mesquite Regional Landfill within a thick sequence of Bear Canyon Conglomerate. The conglomerate is poorly stratified, dense, well consolidated sandstone, conglomerate and breccia which is variably cemented with calcium carbonate and/or clayey matrix. The rock core for a nearby continuously cored borehole (ESI-1) was logged with approximately 50 percent of the core having a silty or clayey matrix. Packer tests in other borings indicate low permeability (i.e., 10^{-6} to 10^{-7} cm/sec).

2. Monitoring Well GW-1 was originally installed in 1988 as part of the Mesquite Mine heap leach pad monitoring well network. The well is screened from -317 to -416 feet below top of casing with a total of 101 feet of screen.

3.0 PUMPING TEST

1. The pumping test of Monitoring Well GW-1 was performed by Environmental Solutions, Inc. in December 1992. A low yield was expected, and the test was performed as a single well pumping test with no other wells monitored.

2. Pumping test parameters are summarized as follows:
   - Constant discharge flow rate = 6.25 gpm
   - Pumping test duration = 805 min
   - Recovery test duration = 35 min
   - Measured maximum drawdown = 12.55 feet
   - Maximum depth to water = 330.15 feet
   - Assumed saturated thickness = 100 feet

3. The flow rate was monitored throughout the test by measuring the volume of discharge into a calibrated container over a measured period of time. Water depth was measured manually with an electric well sounder. The pump used for the test was a Grundfos SP18-2 electric submersible pump installed at a depth of 400 feet below the static water surface.

4.0 PUMPING TEST DATA ANALYSIS

1. The pumping of Monitoring Well GW-1 provided a single well pumping test. Measurement of drawdown provided data for determining transmissivity, but the recovery data period did not continue long enough to provide a well-defined recovery curve.

2. The analysis of Monitoring Well GW-1 data was performed using the Cooper-Jacob straight line approximation method. The drawdown was plotted as drawdown versus log time (Figure I-1) and the slope of straight line segments of the graph are determined over one log cycle.

3. Transmissivity was determined using the formula

$$T = \frac{264\,Q}{A\,(S\text{-}S')} \qquad (1)$$

where T = transmissivity (gpd/ft)
Q = flow rate (gpm)
$A\,(S\text{-}S')$ = slope of straight line segments over one log cycle on the drawdown versus log time graph

4. Permeabilities were determined from the relation:
$T = Kb$
T = transmissivity (gpd/ft)
K = permeability (gpd/ft^2)
b = formation saturated thickness (feet)

---

(1) Reference to Cooper-Jacobs Straight Line Approximation Formula, *Ground Water and Wells*, Johnson Div. U.O.P., page 143, 1975.

5. The calculated hydraulic parameters are summarized as follows:

COOPER-JACOBS STRAIGHT LINE APPROXIMATION	SLOPE ΔS	TRANSMISSIVITY	HYDRAULIC CONDUCTIVITY (Permeability)
Initial Segment	3.8 ft.	= 434 gpd/ft = 58 ft^2/day = 0.0403 ft^2/min	= 0.58 ft/day = 2.1×10^{-4} cm/sec
Secondary Segment	12.4 ft.	= 133 gpd/ft = 17.8 ft^2/day	= 0.18 ft/day = 6.3×10^{-5} cm/sec

6. The recovery data does not extend for a long enough time to define a recovery curve analysis, but the response over the period available appears to be similar to the drawdown curve.

7. Well bore storage may be neglected for a single well test condition in leaky aquifers when:

$$t > \frac{25 r_c^2}{KD} \qquad (2)$$

where t = elapsed time of test (minutes)

r_c = radius of 4-inch diameter casing (feet)

= 0.167 feet

KD = transmissivity

= permeability x saturated thickness (ft^2/min)

= 0.0403 (ft^2/min) for the initial segment

Well bore storage may be neglected for time greater than:

$$t = \frac{25\ (0.167\ \text{ft})^2}{0.0403} = 0.7\ \text{minutes}$$

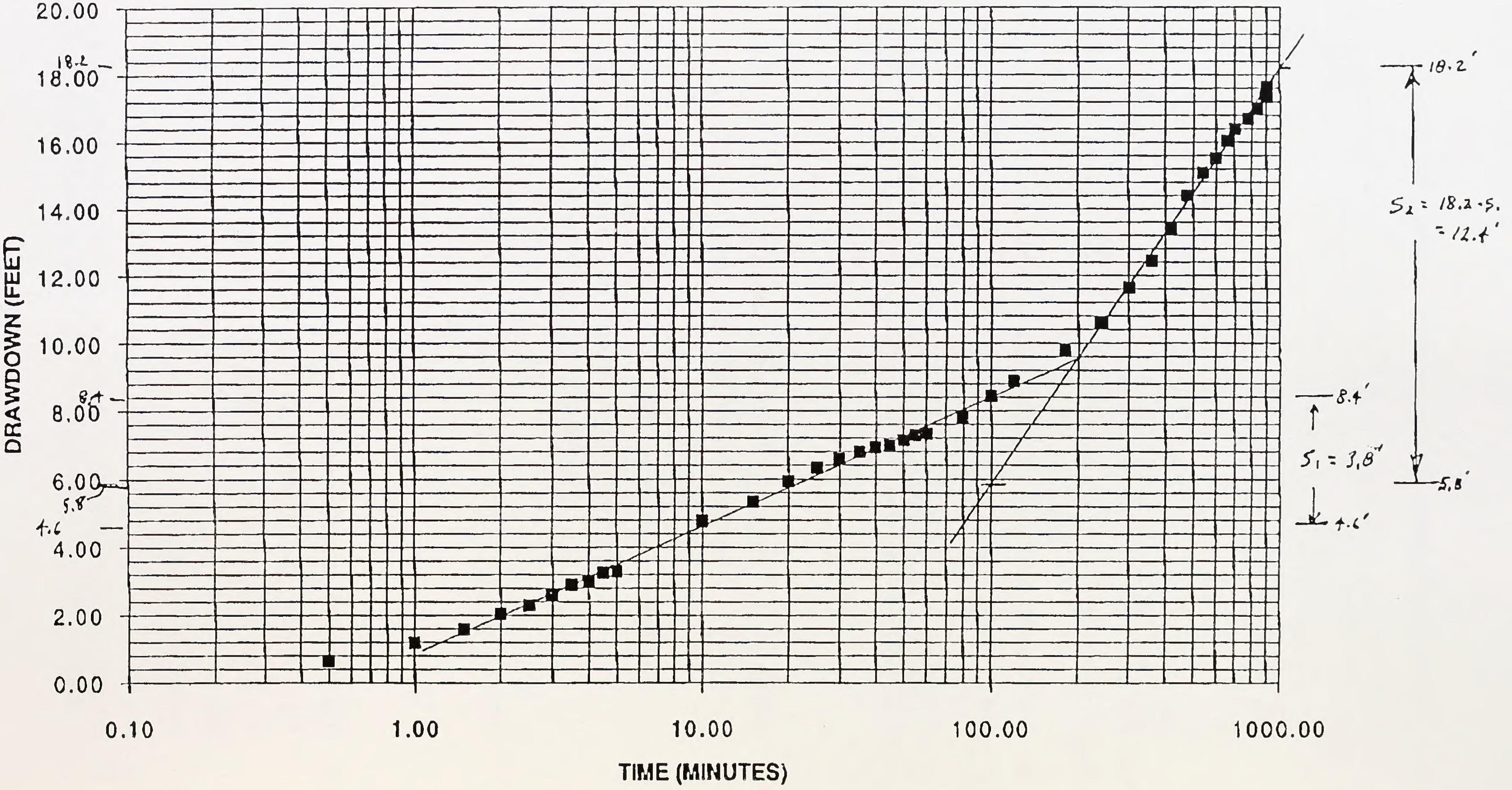
8. The minimum time analysis indicates that both straight line segments of the drawdown versus log time graph may be used for evaluation of formation hydraulic parameters. The indicated formation parameters are interpreted to indicate primary fracture conditions (for the initial segment) and either secondary fracture, or fracture and conglomerate matrix conditions for the secondary segment.

---

(2) Kruseman, G.P., and deRidder, N.A., *Analysis and Evaluation of Pumping Test Data*, Second Edition, Publication 47 International Institute for Land Reclamation, The Netherlands. 1991, Page 223.

FIGURE I-1

MESQUITE (91-296) PUMPING TEST, WELL GW-1



MESQUITE REGIONAL LANDFILL EIS/EIR

APPENDIX C

FAULTING AND SEISMICITY REPORT

DECEMBER 1993

91-296

FAULTING AND SEISMICITY IN THE VICINITY OF THE MESQUITE REGIONAL LANDFILL

December 1993

ENVIRONMENTAL SOLUTIONS, INC.

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APPENDIX B: *CORRELATION AND AGE OF QUATERNARY ALLUVIAL FAN SEQUENCES, BASIN AND RANGE PROVINCE, SOUTHWESTERN UNITED STATES* (GARY E. CHRISTENSON AND CHARLES PURCELL, 1985)

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1.0 INTRODUCTION AND SUMMARY

1. This report discusses the activities and results of a faulting and seismicity investigation conducted to determine potential seismic-related hazards for the proposed Class III Mesquite Regional Landfill in Imperial County, California (Figure 1.1). The primary purposes of this investigation were to:

   - Evaluate the possibility for Holocene faulting (those which have had displacement within the past 10,000 years) within or adjacent to the site; or, if necessary, provide direction for performing additional investigations to more fully evaluate this issue.
   - Analyze anticipated site-specific peak ground accelerations due to area seismicity for use in designing the landfill.

2. Determination of the potential for active (Holocene) faulting to occur at the site is necessary because California Code of Regulations (CCR) Title 23, Chapter 15, Article 3 prohibits the siting of a Class III landfill above a Holocene fault. Recently enacted Subtitle D regulations of the federal Resource Conservation Recovery Act (RCRA) prohibit the siting of a Class III landfill within 200 feet of a Holocene fault.

3. The peak ground acceleration is an important design parameter for assuring that the landfill slopes and cover would remain stable under a reasonable earthquake condition. CCR Title 23 requires that Class III landfills be designed to withstand accelerations due to the Maximum Probable Earthquake (MPE), which is defined as the event with the potential to occur once in 100 years. The Mesquite Regional Landfill would be designed for a larger earthquake than the MPE because of the landfill's long (85-to 100-year) proposed operating life.

4. The basic results of the investigation are that:

   - Published information, onsite investigations and observations, and extensively exposed site desert soils show that Holocene faults do not occur on or near the site.
   - The anticipated peak ground acceleration for the MPE is projected to be approximately 0.17 g (g = the acceleration due to gravity). This acceleration value is not large compared to many areas of California, primarily because the closest active fault is about nine miles away.

5. This peak ground acceleration analysis result is generally confirmed by a recent report titled *Peak Acceleration from Maximum Credible Earthquakes in California,* published by the California Department of Conservation, Division of Mines and Geology (Maulchin and Jones, 1992). This California Division of Mines and Geology (CDMG) report was prepared

specifically for Caltrans in determining appropriate seismic accelerations to be used for designing highways, bridges, etc. It is not considered to be a replacement for existing state fault maps but it does provide valuable information concerning seismic conditions in Imperial County. Figure 1.2 shows the site location with respect to a map from the CDMG report which shows peak accelerations for the Maximum Credible Earthquake (MCE) for various distances from the regional faults considered in that study. The MCE is defined as the maximum earthquake which could potentially occur in the area based on the knowledge of the tectonic framework, and is larger than the MPE. As shown in Figure 1.2, peak ground acceleration at the site of the proposed landfill due to the MCE is estimated by the CDMG report to be slightly less than 0.2g.

6. Activities and results of the faulting and seismicity investigations conducted for the proposed Mesquite Regional Landfill are discussed in the following chapters:
    - Chapter 2.0 - Geologic and Tectonic Setting
    - Chapter 3.0 - Site Geologic Conditions
    - Chapter 4.0 - Site Investigations and Results
    - Chapter 5.0 - Regional Faulting
    - Chapter 6.0 - Seismicity

7. References are listed in Chapter 7.0. Key references are provided in the following appendices:
    - Appendix A - *Soil-Geomorphic Age Assessments of Piedmont Alluvial Fans, Mesquite Regional Landfill Site, Imperial County, California* (Shlemon, 1993); and *Quaternary Soil - Geomorphic Relationships, Southeastern Mojave Desert, California and Arizona* (Shlemon, 1980).
    - Appendix B - *Correlation and Age of Quaternary Alluvial Fan Sequences Basin and Range Province, Southwestern United States* (Christenson and Purcell, 1985).
    - Appendix C - *Mesquite Mining District, Southeastern California, SEG Field Trip* (Tosdal, et al., October 1991).
    - Appendix D - Letter to Environmental Solutions, Inc. *Response to Questions -Draft Report - Faulting and Seismicity in the Vicinity of the Mesquite Regional Landfill*, 1992.

8. Appendix E provides field data discussed in Chapter 4.0.

2.0 GEOLOGIC AND TECTONIC SETTING

1. The project site is located on the western flank of the Chocolate Mountains near the boundary between the Colorado Desert and Mojave Desert Physiographic Provinces of California (Figure 2.1). The Chocolate Mountains, located north and east of the site are part of the Mojave Desert Province. The Imperial Valley, located west of the site, is part of the Colorado Desert Province. The structural feature forming the Imperial Valley is the Salton Trough, which developed as a result of crustal spreading between the North American and Pacific Tectonic Plates along the San Andreas Fault System. Seismicity associated with crustal spreading continues to occur today, primarily associated with active fault systems located 26 or more miles west of the site.

2. The trough represents a northward extension of rifting that, from Pliocene time (2 to 5 million years ago) to present, has separated Baja California from the mainland of Mexico along what is now the Gulf of California. Spreading progressed northward into the Salton Trough from the Gulf resulting in the widening and elongation of Imperial Valley. Large horizontal displacements (transverse faulting) along the San Andreas Fault System, now oblique to the Gulf Trend, formed the eastern boundary of the Salton Trough. As the Gulf and Salton Trough continued to open, a thick sequence of sediments were deposited which initiated subsidence along block faults at the flanks of Imperial Valley.

3. The Salton Trough is significant because it represents an active divergent plate boundary with a transform-pull-apart system. Blocks of terrain have moved upward, downward and nearly horizontally. The trough forms a prominent depression between the Peninsular Ranges on the west and the ranges of the Mojave Desert on the east. The mountains have provided a source for sediments to accumulate in the sunken crustal block of the Salton Trough. The sediments have attained a thickness of over 30,000 feet in the center of the trough. The geologic processes include extension and horizontal and oblique slip, accompanied by volcanism and high heat flow and metamorphism in the crust and overlying sediments. The major active northwest trending San Andreas, San Jacinto and Elsinore Faults project through the greater Salton Trough rift zone. These and several other associated faults within the region have historically ruptured the ground surface and/or caused substantial earthquakes indicating rifting is actively taking place.

4. The Mojave Desert, eastward of the project site, consists of northwest trending rugged mountain ranges separated by broad low relief alluvial-filled basins, or aggraded plains.

The fault controlled mountain ranges and intervening basins are similar to those observed in the Basin and Range Province of Nevada and east-central and southern California but are not as extensive. The Chocolate Mountains are characterized by sharp relief and are included in a series of discontinuous northwest aligned ranges inclusive of the Orocopia and Cargo Muchacho Mountains, all of which lie adjacent and to the east of the Salton Trough.

5. Jennings (1975 and 1992) infers a rather continuous, northwest trending and parallel system of faults within the ranges. Studies by Murry, et al., (1980), have shown that the faults within the ranges are not genetically nor temporally related to the San Andreas Fault System. The faults mapped are short, discontinuous and do not display lateral slip or large amounts of displacement.

6. The Chocolate Mountains (Figure 2.2) are composed of a wide variety of rock types and ages inclusive of:
   - Precambrian (greater than 570 million years old) and Mesozoic (65 to 225 million years old) metamorphic and igneous intrusive rocks.
   - Tertiary (2 to 65 million years) volcanic rocks and nonmarine conglomerates.
   - Quaternary (less than 2 million year old) alluvium.

   Structurally, the Chocolate Mountain range consists of a broad antiform which trends to the northwest.

7. Flanking the western side of the Chocolate Mountains is a broad low relief piedmont surface that gently slopes from the foot of the range toward the floor of the Salton Trough. Within the site region, a thin mantle of alluvial outwash debris overlies bedrock composed of nonmarine upper Miocene (5 to 11 million years old) to lower Pliocene (3 to 5 million years old) Bear Canyon Conglomerate (Dillon, 1975; Morton, 1977) and basement rock composed of older metamorphic rocks. The buried bedrock and basement rock surface, or pediment, was eroded and plainated as the mountain front receded. Prior to the erosion of this pediment, Bear Canyon Conglomerate was deposited adjacent to the mountain front. The Bear Canyon Conglomerate rock unit consists primarily of sandstone, conglomerate, breccia and siltstone, with some interlayered basalt flows.

8. Preceding and accompanying deposition of the Bear Canyon Conglomerate, faulting occurred, breaking the terrain up into discrete fault blocks with distinct rock types (Tosdal, et al., 1991). Two sets of faults have been identified within the open pits of the Mesquite Mining District.

An older set strikes to the northwest and is contemporaneous with the Oligocene age (22.5 to 37.5 million years old) mineralization of the Mesquite ore bodies. A younger fault set strikes to the northeast and displays left lateral oblique slip faulting which resulted in the displacement the Bear Canyon Conglomerate, and possibly early Pleistocene age (1 to 2 million year old) alluvium. Eroded fault block remnants (inselburgs) such as Brownie Hill and Chocolate Drop still protrude above the piedmont surface in the greater site region.

3.0 SITE GEOLOGIC CONDITIONS

1. The proposed landfill site is situated on an alluviated pediment surface, about two miles southwest of the Chocolate Mountains front and about six miles from the Algodones Dunes at the base of the piedmont slope. The site lies between elevations of 560 and 730 feet above sea level. The ground surface has little relief except for the general grade down to the southwest at about 80 feet per mile. Numerous old and active braided stream courses converge and diverge over the surface with a very conspicuous drainage pattern associated with alluvial fans and outwash plains. The active younger drainages are incised into older alluviated perched surfaces. Surface flows are intermittent, occurring only after periods of heavy runoff. Small flows infiltrate into the shallow loose soil in the channel bottoms and/or evaporate. Infrequent larger flows terminate at the Algodones Sand Hills which form a natural topographic constraint between the site area and the floor of the valley.

2. Three ages of alluvial deposition are recognized on the project site as shown in Plate I. The youngest unit is of Holocene age (less than 10,000 years old) and is constrained to the active channel floors. It consists of unconsolidated sands and gravels with a generally low silt fraction. The intermediate alluvial unit is represented by a sequence of perched alluvial fan surfaces that lie up to 4 feet above the active channels. The intermediate alluvium is slightly coarser grained than the younger recent alluvium, being composed of poorly consolidated sand, gravel and silt that has undergone slight weathering. A moderately-developed desert pavement and desert varnish have formed on the detritus. The weathered surface of the intermediate alluvium ranges between late Pleistocene and early Holocene age (8,000 to 17,000 years old) (Shlemon, 1993). The third alluvial unit, the old alluvium, is represented by the highest alluvial fan surfaces, which are perched up to 8 or more feet above the intermediate age alluvial surfaces. This old alluvium unit is very conspicuous and widespread with a distinct yellowish red (5YR 5/8, 5/6) color. The old alluvium consists of poorly consolidated sands and gravels that are slightly indurated and weathered. The old alluvium surface displays a very continuous and well-developed desert varnish and desert pavement (patina), and well-developed desert soil horizons. The old alluvium surface is of late Pleistocene age (35,000 to 40,000 years old) (Shlemon, 1980 and 1993, and Christenson and Purcell, 1985), having undergone at least one pluvial cycle. Beneath the surface soil the old alluvium is estimated to be 60,000 to 70,000 years of age (Oxygen-Isotope Stage 3).

3. All three alluvial units were deposited as fanglomerates derived locally from the Chocolate Mountains. The maximum alluvial thickness overlying the bedrock and basement rock pediment is judged to be about 20 feet, though it varies due to an uneven buried bedrock surface. Lacustrine (lake) deposits associated with the recent Salton Sea, or ancient Lake Cahuilla that previously occupied the Imperial Valley Floor, inclusive of the old shorelines, lie far to the west of the site area and below an elevation of 100 feet.

4. Below the alluvium is a bedrock unit known as the Bear Canyon Conglomerate. This unit is exposed in three isolated outcrops (Plate I) in the north-central portion of the project site as well as in the mine pits to the north. Section views of this unit are shown in Figures 3.1 and 3.2. The Miocene-Pliocene age Bear Canyon Conglomerate consists primarily of massive beds of conglomerate, breccia, sandstone and siltstone. Clasts within the formation consist of granitic and gneissic rocks with a subordinate constituent of volcanics. Interlayered with the nonmarine sediments are vesicular olivine basaltic lava flows that are distinctly dark gray, very hard and range up to about 10 feet thick. Weathering is slight and the beds are slightly to moderately well-cemented with calcium carbonate and/or a clayey matrix. Formational thickness is judged to be at least 1,000 feet. Exposure in the Vista Mine Pit to the northeast of the proposed landfill site indicates that in the site area, the lower 100 (plus) feet consists of bedded lacustrine claystone.

5. Both Brownie Hill and Chocolate Drop to the north and northwest of the proposed landfill site, respectively, are composed of the Bear Canyon Conglomerate (Plate I). These hills are mantled with a thick accumulation of hard basalt clasts that provide an erosion-resistant armor. Derivation of the formation is not known but it most likely was deposited from local sources in the Chocolate Mountains. The formation has been structurally deformed by faulting along northeast trending faults. These northeast trending faults have been documented in the mine pits to the north, and are further discussed in Chapter 4.0. Dip angles measured from recovered core from borings drilled on the proposed landfill property range between 10 and 30 degrees with dip directions toward the west to southwest. Over most of the proposed landfill site, the Bear Canyon Conglomerate underlies the surface at depths of about 20 feet or less.

6. The alluvial units and the Bear Canyon Conglomerate are underlain by pre-Tertiary age (greater than 65 million years old) basement rocks which consist generally of biotite and hornblende gneisses, muscovite schist and pegmatite dikes. Foliation in the rocks is well developed and normally strikes to the northwest and dips east at high to moderate angles.

Where exposed at the ground surface, the basement rock is very fractured and moderately weathered, though hard and sound. In the site area, the depth to basement rock varies from zero at outcrops to at least 1,000 feet based on drill hole data.

7. Small isolated outcrops of metamorphic gneiss basement rock are exposed in the western portion of the site (Plate I). Two other similar outcrops lie to the southwest of the site and collectively indicate a basement high which matches a gravity high anomaly measured in the site vicinity as further discussed in Chapter 4.0. The depth to basement rock as interpreted from lithologic logs of exploration borings is shown on Plate II.

8. South of the proposed landfill site, near the Mesquite Mine water production well field, the shallow bedrock and basement rock pediment surface terminates, and Quaternary alluvial deposits thicken rapidly (Figure 3.1). Water production wells for the Mesquite Mine are located approximately three miles south of the proposed landfill footprint. These wells were drilled in alluvium to depths of about 820 to 940 feet. Basement rock or bedrock was not encountered.

4.0 SITE INVESTIGATIONS AND RESULTS

4.1 BACKGROUND AND SCOPE

1. Exploration, facility development, and mining at the adjacent Mesquite Gold Mine has included extensive data collection and geologic-related investigations resulting in a thorough understanding of the proposed landfill project area. Additionally, considerable data and studies are available for the overall project region because of scientific and economic interests in the Imperial Valley (e.g., plate boundary mechanisms, geothermal and mineral development, etc.). The extensive existing local and regional data base was used for this faulting and seismicity study, as well as additional site-specific field geologic investigation conducted to supplement existing data where required. Geologic data and investigations utilized for this study included:

   - Drilling logs from borings completed to explore for gold mineralization and define the extent of the ore bodies. Since 1981, several thousand exploration borings have been drilled in the vicinity of the proposed landfill project. Most of these have been in the Mesquite Mine pit areas, but many were also drilled in adjacent areas to define the limits of mineralization and to verify that gold ore does not occur beneath the process facility (e.g., heap leach pad) areas. Most of these holes, which typically extend to depths of 200 to 400 feet or more, encountered basement rock. Detailed logs of near surface materials were not prepared for exploration borings. However, depth to basement rock was always logged, when encountered. For this study, data from exploration borings shown in Figure 4.1 was used to determine the depth and configuration of basement rock (Plate II).
   - Drilling logs from additional borings in the site vicinity drilled for geotechnical information and subsurface monitoring. These borings are also shown in Figure 4.1 and were used to provide additional control points for contouring the basement rock configuration.
   - Results of a suite of geophysical surveys, including seismic refraction, gravity, resistivity, self potential, electromagnetic and aerial magnetic techniques. This information was used to help delineate geologic structure and also to interpret the configuration of buried basement terrain where this information was not directly available from boring logs. The geophysical surveys of most value to this study were seismic refraction and gravity.
   - Data from published and unpublished geologic investigations performed in the site area and surrounding vicinity. Regional mapping and investigations of the western Imperial Valley have been conducted by numerous investigators. More detailed geologic mapping of the site vicinity was conducted by Dillon (1975) and others, and by Gold Fields Operating Co. in the Mesquite Mining District. Subsequently, Environmental Solutions, Inc. mapped the site area specifically for this study. The compiled information was used to develop a comprehensive geologic map of the site area at a scale of 1:24,000 (Plate I).

- Analysis of aerial photographs of the site and surrounding area was conducted for mapping the distribution of the three ages of alluvial surfaces and examining the area for terrain conditions that might be related to surface fault rupture on datable geomorphic surfaces. Color and black and white, stereo photography, dated 1982 (prior to surface disturbances of the Mesquite Gold Mine), 1985 and 1992, at scales from 1:10,020 to 1:30,000 were used.
- Two 500-foot long backhoe trenches were excavated and logged across postulated faults in the site area. Continuity of alluvial beds and lenses confirmed the absence of fault rupture.
- Dr. Roy Shlemon (1993) made a site visit to determine the ages of the older and intermediate age piedmont fan geomorphic surfaces in the site area. Soil-geomorphic techniques for relative age assessments of the surfaces were used by Shlemon. As discussed in Chapter 3.0, the older surfaces have an age of 35,000 and 40,000 years. The surfaces of this age have a wide lateral distribution in the site region.
- Fifteen hand-dug test pits were excavated on old alluvial surfaces to verify their soil-geomorphic age. Discontinuous and overlapping older fan surfaces were used to help validate the absence of faulting in the site area. The age model used for the test pits was configured after criteria developed by Shlemon (1993), and Christenson and Purcell (1985).
- The site and surrounding vicinity was visually analyzed and photographed from an airplane flying passes at low altitude to inspect for possible anomalous terrain, lineaments, or other possible features that could be related to faulting. No evidence was observed to indicate active (Holocene) faulting.

These data and investigations are further discussed in the following sections:

- Section 4.2 - Review of Previous Investigations
- Section 4.3 - Surface Investigations and Geologic Mapping
- Section 4.4 - Subsurface Data Evaluation
- Section 4.5 - Local Faults and Possible Faults
- Section 4.6 - Summary and Conclusions of the Site-Specific Investigations

4.2 REVIEW OF PREVIOUS INVESTIGATIONS

1. An extensive array of published and unpublished investigations has been conducted in the site vicinity and region. Published studies used to evaluate the potential for active faulting to occur in the site vicinity include Jennings (1967, 1975, 1992), Maulchin and Jones (1992), Wesnousky (1986), Morton (1977), Greensfelder (1974) and others. None of the published studies have identified active (Holocene) faults trending through or toward the proposed landfill site.

2. Important unpublished investigations include Dillon (1975), Tosdal, et al. (1991), Heath (1992) and geophysical and technical studies conducted by or for Gold Fields Mining Co.

Data from these studies is discussed in Sections 4.4 and 4.5. As for the published studies, these unpublished materials provide no evidence of features that would imply active (Holocene) faulting in the proposed landfill site vicinity.

4.3 SURFACE INVESTIGATIONS AND GEOLOGIC MAPPING

1. The proposed landfill site is located in a region where the existence of Holocene faulting, if present, would be easily distinguishable. Datable, pre-Holocene age (greater than 10,000 year before present), piedmont fan surfaces are widespread in the site region. These surfaces are key to determining whether Holocene fault rupture has occurred. These old surfaces provide a geologic record of the time between their formation and the present. The site conditions provide a stark contrast to many other areas of California where evidence of faulting may not be as straightforward due to vegetative cover, rapid geologic change due to high rainfall, unstable slopes, etc., and other factors.

2. The older alluvial fan geomorphic surfaces in the site area are of late Pleistocene age (35,000 to 40,000 years old). If late Pleistocene or Holocene faulting had occurred in the site area, there would be geomorphic evidence on these surfaces, such as lineaments, offset drainages, depressions, scarps and etc. In the dry desert environment, these types of evidence usually are longstanding. The fault study conducted failed to find any evidence that indicates faulting exists on these surfaces within or near the landfill footprint.

3. Because the relative age of the alluvial fan geomorphic surfaces is a key control in establishing the minimum length of time that has passed since faulting may have occurred in the site area, Dr. Roy Shlemon, an independent, recognized expert in the field of soil stratigraphy, was consulted for this study. Relative soil-geomorphic age assessments of the local piedmont alluvial fan geomorphic surfaces were documented by Dr. Shlemon (1993). His report of findings is included in Appendix A. Based on site reconnaissance from the air and ground, and measurement of soil profiles from two test pits, Shlemon assessed the development of soil (pedogenic) profiles for the old and intermediate alluvium geomorphic surfaces. These test pits were located adjacent to the 500-foot long trenches and are shown in Plate I. Plate I also shows the lateral distribution of the prominent old and intermediate surfaces identified in the site region. The intermediate age fan surfaces are designated as "Qil" and the older surfaces as "Qtol." The youngest alluvium ("Qa" on the map) represents active channels and generally lack soil profiles.

4. The intermediate alluvium surface is typified by a moderately-developed desert pavement and patina with thin vesicular and incipient argillic horizons. As discussed in Chapter 3.0, Shlemon assigned a relative age of 8,000 to 17,000 years (Holocene to Late Pleistocene) to this intermediate alluvium geomorphic surface. It is no older than Stage 2 of the oxygen-isotope stage chronology.

5. The old alluvium geomorphic surface formed during a period of relative landscape stability (oxygen-isotope Stage 3) and has been subjected to at least one soil pluvial epoch. The surface has a well-developed desert pavement and patina and moderately developed soil profile with a vesicular and argillic horizon and multiple calcic horizons. These soils have been forming for the last 35,000 to 40,000 years and are considered pre-Holocene in age. The parent alluvial fanglomerate deposits have an estimated age of 60,000 to 70,000 years. The old fan surfaces are conspicuous and lie as much as 8 to 20 feet above the active channels and generally display broad low relief topographic divides.

6. To further characterize their relative age and distribution, the three alluvial surfaces were mapped from aerial photographs based on their relative height above the active channels, degree of incision, development of topographic divides and degree of patina albedo (reflectance). During the aerial photographic analyses, the surfaces were studied for possible fault-related features such as lineaments, tonal contrast, offset drainages, depressions, and scarps. No evidence for Holocene age (last 10,000 years) faulting was found by these analyses.

7. Field verification of the mapped surfaces was performed by driving, where permitted, or walking main active drainages where stream erosion provided exposures of the soil profiles of the intermediate and old alluvial surfaces. The exposures were inspected for continuity of bedding and lenses. If faulting was present, bedding and lenses could show offset. No evidence for Holocene faulting was identified during the field verification study.

8. Field verification also included hand-excavation of 15 shallow test pits on old alluvium surfaces throughout the site vicinity to confirm the relative age of the surfaces. Criteria used to determine the age of surface soils followed that developed by Shlemon, (1980 and 1993). Plate I shows the location of the test pits. Table E.1 in Appendix E summarizes the thicknesses of the horizons measured. All of the test pits excavated confirmed soil chronology similar to that assigned by Shlemon for the old alluvium geomorphic surfaces.

4.4 SUBSURFACE DATA EVALUATION

1. During the exploration phase of development for the Mesquite Mine, a suite of geophysical surveys was conducted to delineate potential mineralized zones. A second suite of geophysical surveys was conducted in the vicinity of the Mesquite Mine production well field to help locate a suitable ground water source for the mining operations. Of most importance to this study were: (1) a Bouguer gravity survey which covered the entire site vicinity; and (2) an approximately 6.8-mile-long seismic refraction line that included a segment trending along the east side of the landfill footprint. Data from these geophysical surveys, augmented by depth to basement rock data from exploration borings, was used to evaluate whether subsurface features are present in the area that may be related to faulting.

2. The Bouguer gravity data (Plate III) show positive relief in the area known to be underlain by a buried basement rock high based on exploration drilling data and basement rock outcrops near the center of the high. The gradient outward from the high is judged to roughly reflect increasing depth to the eroded and buried basement rock surface. Although the relationship is not direct because of variations in basement rock and bedrock density and other influences, it is apparent that steep linear gradients that often form along faults are not prevalent. The lack of steep relief suggest an eroded relatively shallow buried basement terrain.

3. The refraction profile was run in a general north-south direction across the alluvial surface as shown in Plate II. Results are shown in Figure 4.2. The profile shows a thin low velocity layer (1,800 to 2,000 feet per second) at the ground surface which represents the Pleistocene and Holocene alluvial cover. An intermediate velocity layer (4,600 to 8,300 feet per second), north of the Vista Wells, portrays the Bear Canyon Conglomerate. This intermediate layer overlies basement rock or well-cemented Bear Canyon Conglomerate that has a velocity of 9,500 to 11,500 feet per second. The three velocity layers are undulatory but continuous near the proposed landfill site.

4. In the vicinity of the Mesquite Well Field Wells, two areas of velocity discontinuity were identified. The near surface alluvial sequence remains thin and continuous across the discontinuities. Two underlying velocity layers ranging between 3,500 to 4,300 and 6,300 to 6,400 feet per second were measured and are comprised of saturated semiconsolidated ancient alluvial and lacustrine deposits based on deep water well data.

5. The discontinuity near Station AA (Figure 4.2) just north of the well field is estimated to represent the distal edge of the buried basement pediment surface. Basement rock south of this feature rapidly deepens toward the basin. This feature may represent an old buried normal fault (postulated) as discussed in the following section. If this feature is a fault, it is no longer active as evidenced by the lack of geomorphic expression at the surface and the continuity of the upper low velocity layer.

4.5 LOCAL FAULTS AND POSSIBLE FAULTS

1. As can be seen in Plate I, the detailed mapping that has been conducted by Gold Fields in the immediate vicinity of the mine pits, based primarily on pit exposures and extensive subsurface drilling data, has identified extensive faulting that is confined to basement and bedrock that is pre-Holocene in age (greater than 10,000 years before present). One of the northwest trending faults in the pit area was identified by previous investigators. In addition to these mine pit area features, three features that could be buried faults were identified by this study. The mine pit faults and the three additional possible fault features identified are discussed in the following sections:
   - Section 4.5.1 - Mine Pit Faults
   - Section 4.5.2 - Mesquite Mine Production Well Field Area Feature
   - Section 4.5.3 - Brownie Hill - Blue Hill Feature
   - Section 4.5.4 - Basement High Outcrop Feature

4.5.1 MINE PIT FAULTS

1. Detailed geologic mapping has been performed in the mine pits as they have been excavated. Plate I shows the major faults mapped within and adjacent to the pits as reported by Tosdal, et al. (1991). Two dominant sets of faults have been identified in the pits, an older set trending to the northwest and a younger set trending to the northeast and offsetting the older faults.

2. One northwest trending fault that trends through the Vista Pit and immediately north of the Big Chief pit and Brownie Hill was previously identified by Morton (1977), Higgins (1990) and Crandall (1982). This fault is located about 4,000 feet north of the proposed landfill footprint. It forms a strong aerial photographic lineament up to 1,000 feet wide across the basement rock exposures that is evident in the photographic base of Plate I. As mapped by Gold Fields' geologists, the zones consist of several cross-cutting northwest and northeast

trending faults. These faults are confined to bedrock and basement materials and do not project into the alluvial units. Additional information about the geology and faulting in the mine district is presented in a professional paper by Tosdal, et al., (1991) in Appendix C.

3. A few of the northeast trending faults mapped in the pits displace bedrock and basement rock that are at least as old as the Miocene-Pliocene age (11.2 to 3.4 million years old) Bear Canyon Conglomerate. No evidence has been established to indicate that any of the mapped mine pit faults project up into or through the old alluvium surfaces (35,000 to 40,000 years of age). Analysis of premine development aerial photographs failed to show any lineaments or other fault-related geomorphic features that could be associated with rupturing of these surfaces.

4.5.2 MESQUITE MINE PRODUCTION WELL FIELD AREA FEATURE

1. As discussed in Section 4.3, a basement discontinuity projects roughly east-west in a zone about 3,000 feet north of the Mesquite Mine production wells as shown in Plate I. This feature is approximately aligned with seismic refraction and other geophysical anomalies identified by Alberio (1984), and corresponds with a rapid thickening of alluvial deposits.

2. This feature is believed to represent the distal edge of the basement/bedrock pediment surface and the buried ancient boundary between the Chocolate Mountains and the Salton Trough. A buried normal fault may exist at this location with down-to-the basin displacement. The feature lies at least 8,000 feet to the south of the proposed landfill footprint. No evidence was found to indicate that this possible fault may displace the old alluvial surfaces that are 35,000 to 40,000 years of age.

4.5.3 BROWNIE HILL - BLUE HILL FEATURE

1. Plate I shows a possible fault that trends west-northwest between the southerly foot of Brownie Hill and Blue Hill. A possible fault is postulated at this location due to the basement rock configuration (Plate II) and the alignment of bedrock (Bear Canyon Conglomerate) hills. The structural relationship of this possible fault is shown in Sections A-A' and B-B' in Figure 3.1. Gravity data (Figure 4.1) does not support the presence of this structure, however. An eroded basement rock surface is a possible alternative explanation for the increasing depth to basement.

2. A 500-foot long backhoe trench (Trench No. 1 in Plate I) was excavated across the feature in an attempt to locate the postulated fault. The trench was dug to a depth of 4 to 5 feet into well-bedded old alluvial deposits 60,000 to 70,000 years in age (below 35,000 to 45,000 year old surfaces). A log of the trench is shown in Figure 4.3, and typical photographs of the trench and trench location are shown in Figures 4.4 and 4.5. Soil stratigraphic criteria developed by Shlemon (1993) was used to describe the soils exposed in the trenches, as outlined in Table 4.1. Very good continuity of beds and lenses of fluvial deposits was established along the trench. No evidence of faulting was found nor were any fault-related features noted in the trench. The conclusion of this trench investigation is that if this feature is in fact a fault, it has not moved in the last 60,000 to 70,000 years.

4.5.4 BASEMENT HIGH OUTCROP FEATURE

1. A mostly buried basement high is known to exist in the western-central portion of the proposed landfill footprint based on isolated outcrops of pre Tertiary age (greater than 66.4 million years old) metamorphic rocks and from subsurface drilling data. Subsurface drilling data also showed a basement low between Brownie Hill and the northern-most of these basement rock outcrops (Plate II). The buried basement low may be an erosional feature or it may be bounded on the northeast by a down-to-the-north normal displacement fault. This postulated fault would trend to the northwest, similar to the Brownie Hill - Blue Hill feature.

2. Another 500-foot long backhoe trench (Trench No. 2) was excavated across this feature at the location shown in Plate I. The trench log is shown in Figure 4.6 and typical photographs of the trench are shown in Figure 4.7. The trench was excavated across an intermediate alluvium surface that has a relative age of 8,000 to 17,000 years of age (Shlemon, 1993). The age of the subsurface alluvium is estimated to be older than the overlying soils and in excess of 10,000 years old (late Pleistocene). No evidence for faulting was noted based on the continuity established among well-bedded layers and lenses.

4.6 SUMMARY AND CONCLUSIONS OF THE SITE-SPECIFIC INVESTIGATIONS

1. As discussed in the preceding sections, no evidence for Holocene faulting (last 10,000 years) was detected on, or immediately adjacent to, the proposed landfill footprint. This study concludes that the site is clear of Holocene faults based on the following:
   - All previous mapping conducted by state and federal agencies, and investigations associated with universities and industry, have not identified active (Holocene) faults trending through or toward the project site. The area is considered to be in a relatively stable tectonic zone.

- Detailed geologic mapping of adjacent mined areas conducted by Gold Fields Mining Co. has not identified active (Holocene) faulting.
- Aerial photographic imagery analyses with subsequent field verification did not indicate evidence of Holocene faulting.
- Analysis of geophysical data and extensive drilling information in the site area helped delineate buried geologic structures that were evaluated to determine whether there may be evidence of faulting below the ground surface. Trenches were excavated at two locations where possible faults were postulated based subsurface data. Data from these trenches did not indicate any evidence for Holocene faulting.
- Continuous and overlapping pre-Holocene age fan surfaces project through large portions of the site region. The older surfaces have a relative age of 35,000 to 40,000 years, and provide a dependable controlling factor for determining the presence or lack Holocene faulting. No evidence of Holocene faulting was identified trending across any mapped surface in the project study area.
- As further discussed in Chapter 6.0, historic seismicity in the region has been very low suggesting the site does not lie in a zone of active faulting. Active faulting related to the present tectonic regime is associated with the Salton Trough spreading center, located a minimum distance of nine miles to the west of the site as discussed in Chapter 5.0.

5.0 REGIONAL FAULTING

5.1 BACKGROUND AND SCOPE

1. As discussed in Section 2.0, the proposed landfill site is located near the western margin of the Salton Trough, which represents an active tectonic plate boundary with ongoing crustal spreading and transform faulting. The site is located east of the Salton Trough in an area that is considered tectonically stable. Active faulting associated with the regional tectonics of the Salton Trough begins occurring a minimum of nine miles west of the proposed project site. This chapter discusses faults in the region that are important to consider so that landfill facilities can be designed to preclude unacceptable damage by earthquake ground shaking.

2. The Salton Trough is one of the most studied features in the world because of its continuing tectonic activity and associated geothermal systems. Hundreds of professional papers have been written by some of the most acclaimed geologists and seismologists. The tectonic processes of the region are relatively well understood compared to other active regions. Earthquakes and fault ruptures occur frequently and are studied in great detail. Substantial subsurface information is available for these studies from deep exploration wells in geothermal areas. Suites of various geophysical surveys have been used to examine the structure and stratigraphy within the trough. Intensive investigations for faulting and earthquake activity have been conducted by industries for nuclear facilities and mineral, energy and water resources.

3. This investigation conducted for determining which faults and associated earthquakes might influence the proposed landfill included:
    - Researching pertinent available published and unpublished professional papers and reports prepared by federal and state agencies, universities and individuals. A list of the literature researched is included in Chapter 7.0, References. Two of the most current papers prepared by the California Division of Mines and Geology (Maulchin and Jones, 1992, and Jennings, 1992) include fault maps that show the location of regional capable faults, and provide MCE magnitudes and activity rating for the regional faults.
    - Mr. Edward Heath (1992), an independent Consulting Geologist, was retained for this study because of his knowledge of the regional tectonics in the Salton Trough. Heath previously conducted studies for a nuclear facility south of Yuma, Arizona. Heath's previous studies consisted of investigating faults along the east side of the Salton Trough with geophysical techniques (seismic reflection), fault trenching and aerial photographic analyses. Information derived by Heath was instrumental in determining which regional faults and associated earthquakes might influence the proposed landfill.

- Fixed-wing, low altitude aircraft observations and photography were employed to help validate geomorphic features that could be useful for establishing an age limit of faulting in the Sand Hills area opposite the project site.
- USGS National Earthquake Information Center computer records were obtained and evaluated for earthquakes that have occurred historically within a 100-kilometer (approximately 60 miles) radius of the proposed landfill site.

4. Major regional faults identified for this study are shown in Figure 2.1. Seismologists have assigned MCE magnitudes to the known active faults. The MCE event is considered the largest possible earthquake based on the known tectonic framework of a particular fault. A second design earthquake, the MPE is the largest earthquake on a particular fault which has a 100-year return period. The MPE is deduced from many sources of information such as: (1) historic seismicity; (2) fault rupture dimensions; (3) fault segmentation; and (4) empirical data derived from other similar faults or fault systems.

5.2 FAULTS CONSIDERED ACTIVE OR POTENTIALLY ACTIVE

1. This section discusses faults and postulated faults that are important to consider for design of the proposed landfill. Estimated peak horizontal ground accelerations that could occur at the proposed landfill site due to activity on these faults are addressed in Chapter 6.0.

5.2.1 SAN ANDREAS FAULT

1. The San Andreas Fault (Figure 2.1) dominates the present active tectonic regime in the site region. Total lateral displacement in the region has been in the order of at least 180 miles (300 km) in the last four million years (Damiata, et al., 1986).

2. The active southern portion of the San Andreas Fault traverses along the northeast side of the Salton Sea and terminates near Bombay Beach about 45 miles to the northwest of the site (Jennings, 1992; and Maulchin and Jones, 1992; Heath, 1992). The fault displays dominant right lateral slip and consists of several en echelon traces in a wide zone with diverging north trending splays. The southern portion of the fault has not produced a major historic earthquake, though in 1969, during the Borrego Mountain Earthquake (San Jacinto Fault), sympathetic rupture was reported along the east side of the Salton Sea (Jennings, 1975). The southern portion of the San Andreas Fault has been assigned an MCE of 8.25 (Maulchin and Jones, 1992).

5.2.2 BRAWLEY SEISMIC ZONE

1. The current model for seismic and tectonic activity south of the San Andreas Fault is associated with interaction of transform faulting and spreading centers as shown in Figure 5.1. The model depicts the westerly land mass (lower left portion of the figure) moving to the northwest relative to the easterly land mass (upper right portion of the figure), along a series of subparallel northwest trending right lateral en echelon faults, resulting in the land being pulled apart at spreading centers. The northwest trending faults terminate at these centers, though continued transform movements are shifted across the spreading zones to the adjacent transform fault. Figure 5.2 shows earthquake epicenters that delineate the spreading centers opposite the site area and represent the shifting of movement from the south end of the San Andreas Fault to the Imperial-Brawley Fault zone.

2. This zone of crustal rifting and intense seismic activity is known as the Brawley Seismic Zone. The zone lies south of Bombay Beach and west of the Sand Hills (Figure 2.1). No surface faulting has been identified with the zone but numerous small earthquakes have been recorded between the southern San Andreas Fault and the Imperial-Brawley Faults as shown in Figure 5.2. The Brawley Seismic Zone has been assigned an MCE of M6.25 (Maulchin and Jones, 1992).

5.2.3 EAST MESA FAULT

1. A previous study by Heath (1980), indicated several north-south trending, left stepping en echelon faults on the East Mesa that showed normal movement with the west side down-dropped with some possible lateral movement. The faults are located west of the Algodones Sand Hills and project along a five-mile zone. Trenching and logging of the faults showed that rupture was relatively young, possible late Pleistocene or Holocene age.

2. According to Heath (1992), these faults appear to represent active tensional stress along the eastern margin of the Salton Trough opposite the spreading center. This apparent motion, down-to-the-basin normal listric faulting, is related to the pull-apart processes within the spreading center and not lateral slip along the San Andreas Fault. These features may be aseismic and associated with downdropping of the trough, a common basin margin subsidence phenomena. For purposes of this study, these East Mesa Faults are considered active and are the closest active fault to the site. An MCE event of M6.5 is assigned to the East Mesa Fault (Heath, 1992). As discussed in Appendix D, Heath recommended a conservative earthquake scenario that assumes there may be traces of this fault along the western side of the sand hills, approximately nine miles west of the site.

5.2.4 EAST HIGHLINE CANAL LINEAMENT

1. Maulchin and Jones (1992) have reported an active Holocene fault referred to as the East Highline Canal lineament (Figure 2.1). This lineament trends to the northwest and has a mapped length of 40 miles. The feature projects directly along the ancient shoreline of Lake Cahuilla at elevation zero. The shoreline represents a pronounced erosional geomorphic lineament. Whether this lineament is a shoreline fault is considered highly questionable. The only evidence for its existence is the shoreline itself. However, for the purposes of this study, the lineament is considered an active fault. The lineament lies 15 miles west of the project site and has been assigned an MCE of M6.5 (Maulchin and Jones, 1992).

5.2.5 IMPERIAL AND BRAWLEY FAULTS

1. The active Imperial and Brawley fault system (Figure 2.1) is located in a zone of pronounced seismic activity and surface fault rupture. The system trends to the northwest and extend from east of Cerro Prieto in Mexico to near Brawley, a total distance of about 60 miles. Displacement along the fault has been right slip with a small vertical component. The strike of the Imperial Fault is nearly concordant with the San Jacinto Fault northwest of the Salton Sea (Real, McJunkin, Leivas, 1979). The Brawley Fault trends to the north from an intersection with the Imperial Fault at a location about four miles northeast of the city of El Centro. The fault has a surface expression (scarp) of approximately 8.5 miles long. The Mesquite Graben lies between the two faults which have moved synchronously during past earthquakes.

2. In Baja, Mexico, the Imperial Fault appears to terminate at a spreading center similar to the San Andreas Fault in the Salton Trough (Terres and Crowell, 1979). From the site, the Imperial-Brawley system, lies at a minimum distance of 26 miles to the west. An MCE event of M7.0 has been assigned to the system (Maulchin and Jones, 1992).

5.2.6 SAN JACINTO FAULT SYSTEM

1. To the southwest of the Salton Sea and trending to the northwest on line with the San Jacinto Fault are two subparallel faults known as the Superstition Hills and Superstition Mountain Faults (Figure 2.1), both of which are roughly 15 miles long. The 23-mile long active Coyote Creek Fault is probably a continuation of the Superstition Mountain Fault to the northwest. All three faults display right lateral displacement and are considered segments of the San Jacinto Fault which is the most active fault in southern California. Historically,

moderate-sized earthquakes have occurred on these faults accompanied by surface rupture. The project site lies a minimum distance of 37 miles to the east of the faults. The MCE magnitude for the San Jacinto Fault System is M7.5 (Maulchin and Jones, 1992).

5.2.7 ELSINORE FAULT

1. The northwest trending Elsinore Fault is an active fault system lying about 52 miles to the southwest of the proposed landfill site (Figure 2.1). This fault continues south into Mexico where it too ends at an inferred spreading center. The fault consists of many overlapping strands and displays right lateral movement. The Elsinore Fault ruptured the ground surface in 1910 near Lake Elsinore, and historically has produced moderate-sized earthquakes. An MCE of M7.5 has been assigned to the Elsinore Fault (Wesnousky, 1986).

5.3 INACTIVE FAULTS

1. This section discusses faults and postulated faults that have been considered for this study and determined not to be of concern for the proposed project because of lack of evidence for faulting or recent movement.

5.3.1 SAND HILLS FAULT

1. The Sand Hills Fault (Figure 2.1) is a postulated projection of the San Andreas Fault that continues southeast of Bombay Beach and trends along the east side of the Algodones Sand Dunes opposite the site (Jennings, 1992). Due to its proximity to the site (about 4.5 miles), Edward Heath (1992) was retained for this study to determine the appropriate activity rating for this postulated fault. Appendix D contains the report written by Heath describing his finding and conclusions regarding the faulting and seismicity in the vicinity of the project. Some geophysical (seismic reflection) evidence that suggests deep faulting exists along the Sand Hills trend but there is no evidence to suggest Quaternary age (last 2 million years) deposits are displaced. All fault maps prepared by state and federal agencies, as well as professional papers written by experts, show the Sand Hills Fault to be a questionable and buried feature and at no time has the fault been identified to be active or potentially active (i.e., having moved the last 500,000 years, or late Pleistocene time).

2. Based on the current tectonic model of the Salton Trough (Figure 5.1), the San Andreas Fault northwestward from the southeast end of the Salton Sea is considered a transform structure

with dominant right lateral slip. To the southeast, the postulated Sand Hills Fault projection lies opposite the spreading center of the trough where transform movement should decrease to zero. Still further to the southeast, if the model is correct, the Sand Hills Fault should display transform left lateral slip as a relic of past crustal spreading (Sheehan, 1986). The fact that there has been nominal historic seismicity and lack of geomorphic evidence for Holocene activity on the Sand Hills Fault strongly suggests the model is correct.

3. The Sand Hills Fault appears to presently represent an abandoned transform fault that now forms the eastern margin of spreading within the trough. The San Andreas Fault proper apparently ends in the now developing pull-apart spreading basin south of the Salton Sea (Terres and Crowell, 1979; Crowell and Sylvester, 1979) and does not connect with the Sand Hills Fault (Heath, 1992). This condition alleviates the possibility for the Sand Hills Fault to rupture and produce major earthquakes in the vicinity, opposite the site. The Sand Hills Fault is considered inactive and not a seismic constraint relative to the project.

5.3.2 POSTULATED ALGODONES FAULT

1. Faults maps prepared by Maulchin and Jones (1992) and Jennings (1992), show that the Algondones Fault , located about 17 miles east-southeast of the project site is capable of possible future fault rupture. In 1974, Woodward-McNeil, Inc., conducted a geotechnical investigation for a proposed nuclear facility near Yuma, Arizona. An extensive fault investigation was performed to determine, in part, if the Algodones Fault was capable of future rupture or generating a major earthquake. The investigators found that the Algodones Fault was a down-to-the-east normal fault confined to the western margin of the Fortuna Basin in Arizona (Heath, 1992).

2. No evidence was found to indicate the Algodones Fault projected across the Yuma basement high into California. West of the Yuma basement high, west dipping normal faults were identified and these most likely represent the eastern edge of the Salton Trough and are probably related to the East Mesa Fault (Heath, 1992). The Algodones Fault does not exist as mapped by the California Division of Mines and Geology (Maulchin and Jones, 1992; Jennings, 1992) but is shown in Figure 2.1 for descriptive purposes.

5.3.3 CHOCOLATE MOUNTAINS FAULTS

1. Numerous faults have been mapped in the Chocolate Mountains to the north of the project site. The faults mapped are dominantly northwest trending normal or curvilinear thrust faults associated with uplift of the range. All mapped faults are pre-Holocene (Dillon, 1975); Murry, et al., 1980; Higgins, 1990; Jennings, 1992; Maulchin and Jones, 1992). No surface faults have been mapped on the piedmont fans in the vicinity of the project between the foot of the range and the east side of the Imperial Valley. For these reasons, faults within the Chocolate Mountains are not considered active for this investigation.

5.4 SUMMARY AND CONCLUSIONS

1. The active faults assigned a MCE magnitude in Section 5.2 are those that might affect the project should they rupture and produce a substantial earthquake. None of the active faults discussed trend toward or through the property. Of the seven active faults and fault zones identified, the East Mesa Fault is the closest to the site (nine miles). Regionally, earthquake MCE magnitudes range between M6.25 to M8.25 with the larger events associated with the San Andreas, San Jacinto and Elsinore Faults. Chapter 6.0 describes the potential ground motions that can be anticipated at the site from a substantial earthquake.

6.0 SEISMICITY

1. The Imperial Valley is one of the most seismically active regions of California. The pattern and frequency of earthquakes and the types of motions reflect the active tectonic processes. Most of the large historic earthquakes have occurred on the Imperial-Brawley and San Jacinto systems with earthquake sequences occurring as main shocks followed by aftershocks or swarms of small events (Damiata, et al., 1986). Far fewer historic earthquakes are located in proximity of the southern San Andreas Fault indicating the current active tectonic regime is located further to the west in the central and western portions of the Salton Trough.

2. The recent Joshua Tree, Landers, and Big Bear Earthquake Sequence of 1992 has led some investigators to believe the south San Andreas Fault, north of the Salton Sea, is ready to rupture with perhaps another major event. The faults associated with the 1992 sequence were the Camp Rock, Johnson Valley, Galway Lake and Emerson (desert) Faults. Questions remain as to how these faults are associated to the San Andreas system, if at all. The maximum earthquake magnitude was a M7.5 (Landers event of June 28, 1992). Thousands of aftershocks have followed the main sequence within a 60-mile long northwest trending pattern. The project site lies about 100 miles to the southeast of this zone. Employees at the Mesquite Mine felt the large earthquakes, but reportedly shaking was mild and there was no damage.

3. The 1992 Landers Earthquake sequence proved that more than one fault within the same system can rupture simultaneously. As a result, in the event that the southern San Andreas Fault were to rupture, there is a potential for other nearby associated faults with the same tectonic framework to rupture. The anticipated earthquake magnitude of such a combined event is primarily dictated by the fault(s) length and sense of movement. Magnitudes have been assigned to regional active faults that could influence the site and are listed in Table 6.1. Additional fault parameters are provided in Table 6.2. As shown in these tables, if three segments of the San Andreas Fault were to rupture simultaneously between the south end of the Salton Sea (Bombay Beach) and Slack Canyon (near Parkfield, California in San Luis Obispo County) with a total rupture length of 328 miles, a maximum credible earthquake of M 8.25 could occur. However, as is also shown, this would only cause maximum ground acceleration of 0.08 g at the site.

4. Most of the earthquakes occur at relatively shallow depth in the central valley area. Seismicity appears to peak at a depth of about 8 km (4.8 miles) which may be associated with crustal extension and geothermal processes. This crustal extension process results in sedimentation on

the surface and intrusion of mafic igneous rocks into the earth's lower crust within the trough. Accompanying the spreading are high seismicity, high heat flow and metamorphism of sediments at shallow depths.

5. Figure 6.1 shows the distribution of historic earthquake epicenters for events greater than M4.0 occurring within a radius of 100 km (60 miles) of the site based on United States Geological Survey (USGS) National Earthquake Information Center Data obtained in 1992. Within the search radius, there have been 437 earthquakes with magnitudes ranging from 4.0 to 7.0. Earthquakes plotting closest to the site include two events recorded at latitude 33.000, longitude 115.000. These events include a M5.5 in 1872 and a M4.0 in 1943. These early earthquake records are based on limited information so there is little control over epicenter location. The 1872 earthquake location was estimated based on newspaper reports of ground shaking in Yuma and San Bernardino. The epicenter was plotted between these widely spaced locals but is only estimated to have occurred "in or near the Imperial Valley" (Toppozada, et al., 1981). The M4.0 earthquake occurring in 1943 was probably plotted based on similar reports of ground shaking (personal communication, Glen Reagor, United States Geologic Survey, August 6, 1993;) and/or limited southern California regional seismograph stations available at that time (personal communication, Dr. Lucy Jones, United States Geologic Survey, August 6, 1993). The USGS data base designates the accuracy of the 1943 epicenter as a "D" quality location, meaning that the level of confidence of the location is greater than 15 km (9 miles). Because there are no known active faults in the vicinity of these two early epicenters, it is likely that these earthquakes occurred further to the west in the more active seismic region of the Imperial Valley.

6. The most recent moderate-sized earthquakes were the October 15, 1979, Imperial Valley Earthquake (M6.6) on the Imperial-Brawley system, and the November 23-24, 1987, Superstition Hills Earthquakes (M6.2 and M6.6). In the low lying portions of the valley, considerable structural damage occurred due to these events. A large portion of the damage was attributed to liquefaction. Significant historic earthquakes included in the USGS data base are summarized in Table 6.3. This level of seismic activity is expected to continue in the region with the possibility of larger events along the known active faults.

7. As indicated above, Table 6.1 shows the anticipated ground motions at the site from the various known regional active faults should one rupture and produce a major earthquake. The degree of ground shaking is mostly related to the magnitude of an earthquake and the distance from the epicenter to the site. The accelerations shown in Table 6.1 were computed using empirical

deterministic data after Joyner and Fumal (1986). As shown, the worst-case scenario would be a MCE of M6.5, located nine miles west of the site on the East Mesa Fault. Peak horizontal accelerations for such an event would be about 0.20g. For the MPE (M6.0) on the East-Mesa Fault, peak horizontal accelerations would be about 0.17g. The high repeatable accelerations would be 0.13g and 0.11g for the MCE and MPE, respectively.

8. Secondary events sometimes associated with earthquakes include liquefaction, induced landsliding, flooding and subsidence. The potential for liquefaction is not relevant for the proposed landfill site because of the relatively great depth to ground water (i.e., greater than 100 feet), and the dense nature of the underlying natural formations. The site is far enough from upland slopes to preclude the potential for induced landsliding. Landfill slopes and cover would be designed to withstand the anticipated acceleration conditions. The site is far enough from the coast or large inland bodies of water to preclude the hazards of a tsunami or seiche (waves), or inundation from the breaching of an upgradient reservoir. Subsidence is not likely to occur because of relatively shallow bedrock conditions.

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TABLE 4.1

SHLEMON (1993) SOIL STRATIGRAPHIC CRITERIA UTILIZED FOR TRENCH LOGGING

TRENCH 1 - GENERAL SOIL PROFILE MEASUREMENT AND DESCRIPTION FOR OLD ALLUVIUM SURFACE

Geomorphic setting: middle-level geomorphic surface; medial segments, piedmont alluvial fans; moderately to strongly-developed desert pavement; parent material mainly locally-derived basalt with approximately 5 percent quartz fragments; high albedo.

HORIZON	DEPTH (feet)	DESCRIPTION
Av-B1	0.0 to 0.2	Yellowish red (5YR 4/6) to light brown (7.5YR 6/4) silty clay loam; weak moderate angular blocky structure; slightly hard, firm; slightly sticky and slightly plastic; effervescent; abrupt wavy boundary.
B2tk	0.2 - 0.8	Yellowish red (5YR 5/8) to yellowish red (5YR 5/6) when moist; gravely silty clay; massive to weak, very fine subangular blocky structure; soft, friable, slightly sticky and slightly plastic; violently effervescent; common, carbonate nodules, rounded to 0.5 inches diameter; few to common clay films lining ped faces and filling root tubules; very angular clasts to 3 inches diameter near base; gradual wavy boundary.
B3-C1	0.8 to 1.4	Strong brown (7.5YR 5/8) dry and moist; gravely silty loam; massive structure; slightly hard, friable, nonsticky and nonplastic; effervescent; few fine carbonate nodules; very angular clasts to 3 inches diameter (fanglomerate); gradual wavy boundary.
C2	1.4 to 2.5+	Very angular gravely clasts to 3 inches diameter; parent material; locally-derived basaltic fanglomerate.
Estimated soil age 35,000 to 40,000 years for fan surface; based on presence of moderately-developed argillic horizon, presence of disseminated Stage II carbonates in Btk horizon; parent material estimated age 60,000 to 70,000 years.		

TRENCH 2 - GENERAL SOIL PROFILE MEASUREMENT AND DESCRIPTION FOR INTERMEDIATE ALLUVIUM SURFACE

Geomorphic setting: slightly-dissected fan surface; moderately to strongly developed desert pavement; medial piedmont fan segments; high albedo with 90-95 percent of angular clasts derived from local basaltic sources.

HORIZON	DEPTH (feet)	DESCRIPTION
Av	0.0 to 0.1	Pale brown (10YR 6/3) silty clay; weak, very fine subangular blocky structure; hard, firm, slightly sticky and non-plastic; abrupt wavy boundary.
Btjk	0.1 to 0.4	Yellowish red (5YR 4/6) silty clay; moderate medium angular blocky structure; very hard, very firm, slightly sticky and slightly plastic; effervescent; very few, thin clay films lining root tubules; few very fine disseminated calcium carbonates throughout horizon; approximately 20 percent fine angular gravels; gradual wavy boundary.
C1	0.4 to 1.2	Reddish yellow (5YR 6/6) very fine gravely silty clay; massive structure; hard, firm, nonsticky and nonplastic, effervescent; Stage I disseminated carbonate nodules throughout matrix; abrupt wavy boundary.
C2	1.2 to 2.2+	Parent material: very angular gravels to 3 inches diameter; primarily basaltic fanglomerates, locally derived.
Estimated soil age approximately 8,000 to 17,000 years; based on presence of incipient argillic horizon (Btjk) and moderately-developed, undissected desert pavement.		

91-296 (3/12/93/ds)

NOTES:

Soil stratigraphic criteria developed by Shlemon (1993) was used to describe the soils exposed in the trenches and assign an appropriate age for the upper surfaces of the fans. This same criteria was used to map the fan surfaces in the greater site area as discussed in Section 4.3 of this report. Background information on how the ages were determined are discussed in the report by Shlemon in Appendix A and are not repeated here. The above tables (after Shlemon, 1993), describe the soil horizon parameters for the intermediate and older fans surfaces. Trench No. 1 was excavated across the older fan surface and Trench No. 2 was on the intermediate age surface.

For purposes of trench logging, four general soil stratigraphic units were identified for which to establish continuity of beds along the trench walls. The pedogenic soils, as shown on the trench logs (Figures 4.3 and 4.6), are confined to the upper three layers designated as A, B and C, as shown on the logs. These horizons correspond to the descriptions given by Shlemon (1993) for the general A, B and C pedogenic soil horizons. The D stratigraphic unit underlying the pedogenic soil sequence, represents the parent material (a fanglomerate). Unit D is further broken down into five types of fluvial soils for purposes of establishing continuity of layers and lenses:

D1 - Sandy Gravel
D2 - Gravelly Sand
D3 - Sand (generally coarse with some pea gravel)
D4 - Silty Sand (was not logged in trenches)
D5 - Gravelly Silty Sand (25+/- percent angular gravel, mud flow)

TABLE 6.1

EARTHQUAKE PARAMETERS

FAULT	DISTANCE AND DIRECTION FROM SITE (miles)	MAXIMUM EARTHQUAKE (M)		PEAK HORIZONTAL GROUND ACCELERATION (g)		HIGH REPEATABLE ACCELERATION (g)(2)		DURATION OF STRONG GROUND SHAKING (seconds)
		Credible(3)	Probable(4)	Credible	Probable	Credible	Probable	
East Mesa	9, W	6.5	6.0	0.20	0.17	0.13	0.11	18
East Highline Canal Lineament	15, W	6.5	6.0	0.13	0.09	0.09	0.06	18
Imperial/Brawley	26, W	7.0	6.8	0.08	0.07	0.05	0.05	24
Brawley Seismic Zone	29, W	6.25	5.8	0.05	0.04	0.03	0.03	18
Superstition Hill Superstition Mountain (San Jacinto Fault Zone)	37, W	7.5	7.0	0.07	0.05	0.05	0.03	30
San Andreas	45, NW	8.25(5)	7.5	0.08	0.04	0.05	0.03	36
Elsinore	52, SW	7.5	7.0	0.04	0.03	0.02	0.02	30

91-296 (12/11/93/cm)

(1) Joyner and Fumal, 1986.

(2) The highest accelerations that are generally sustained for a period of time during an earthquake and are typically 65 percent of the peak horizontal ground acceleration.

(3) Maximum credible magnitudes shown are Moment Magnitudes (Mw) after Mualchin and Jones (1992) and Slemmons (1982). The surface wave magnitudes (Ms) used by Slemmons (1982) are assumed to approximate moment magnitudes (Mw). The Mw is the appropriate magnitude scale required for estimating peak accelerations from modern attenuation relationships.

(4) Maximum probable magnitudes shown were determined using available data relative to: type and amount of displacement, historic seismic events, and empirical relationships of fault segment rupture lengths versus magnitude after Slemmons (1982).

(5) The maximum credible event was calculated using empirical data after Slemmons (1982) for three segment fault lengths totaling 328 miles.

TABLE 6.2

FAULT PARAMETERS

FAULT	LENGTH (Miles)[1]	FAULT TYPE[2]	SLIP RATE (mm/year)[3]	RECURRENCE INTERVAL (years)[3]
East Mesa	11	N	?	?
East Highline Canal Lineament	34	N(?)	?	?
Imperial/Brawley	41	RV	8.6	700
Brawley Seismic Zone	28	RV	?	?
Superstition Mountain/Hills San Jacinto Fault Zone	141	RL	1 to 10	150 to 468
San Andreas	328[4]	RL	25 to 34	140 to 360
Elsinore	110	RL	4	694

91-296 (12/11/93/cm)

(1) Jennings, 1992.
(2) N - normal, RV - reverse, RL - right-lateral
(3) Wesnousky, 1986.
(4) San Andreas Fault length includes the following three segments:

• Salton Sea to Cajon Pass	126 miles
• Cajon Pass to Highway 166	106 miles
• Highway 166 to Slack Canyon	96 miles
Total Length	328 miles

? - Indicates information not available.

TABLE 6.3

SIGNIFICANT HISTORIC EARTHQUAKES IMPERIAL VALLEY REGION (SINCE 1890)

FAULT	DATE	MAGNITUDE
Brawley-Imperial	1892	6.3
	1940	6.9
	1979	6.4
Superstition Hills, Superstition Mountain and Coyote Creek	1890	6.3
	1892	6.3
	1942	6.5
	1954	6.2
	1968	6.5
	1987	6.2 and 6.6
San Andreas (South)	1937	6.0
	1948	6.5
Elsinore (South)	1892	6.7

91-296 (12/10/93/jtw)

91-296 FS REV. 8/24/92

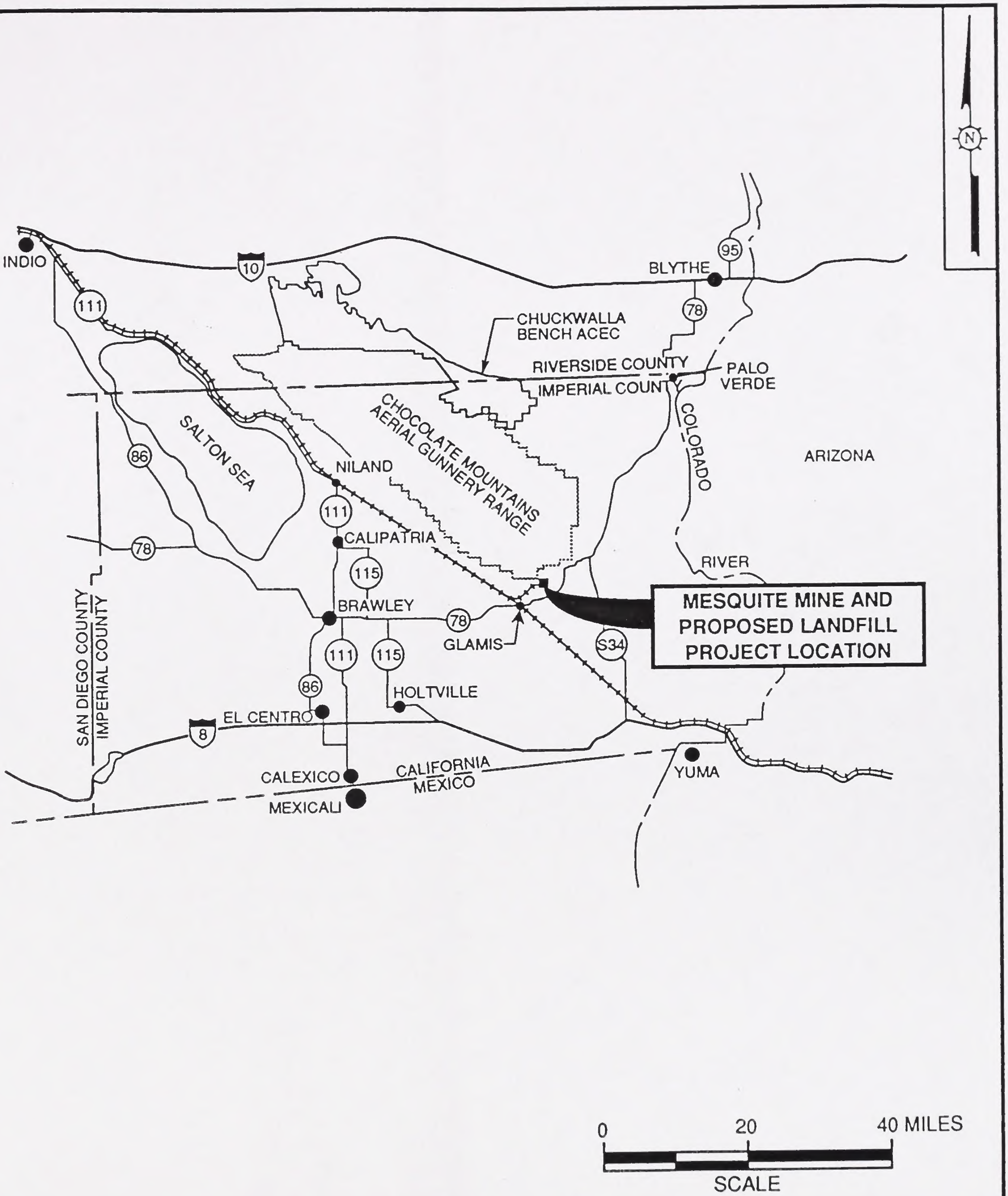


FIGURE 1.1

REGIONAL LOCATION MAP

MESQUITE REGIONAL LANDFILL

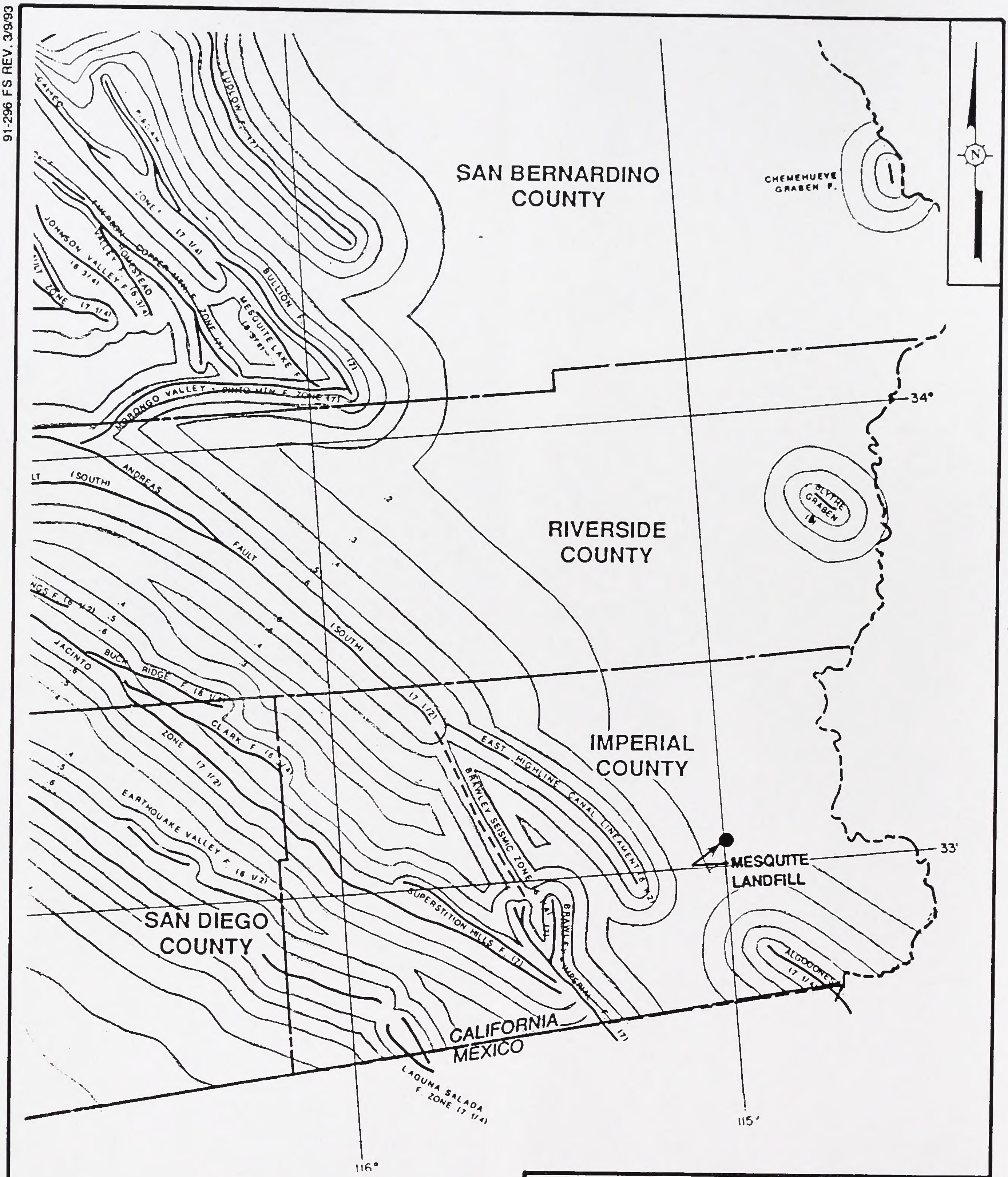


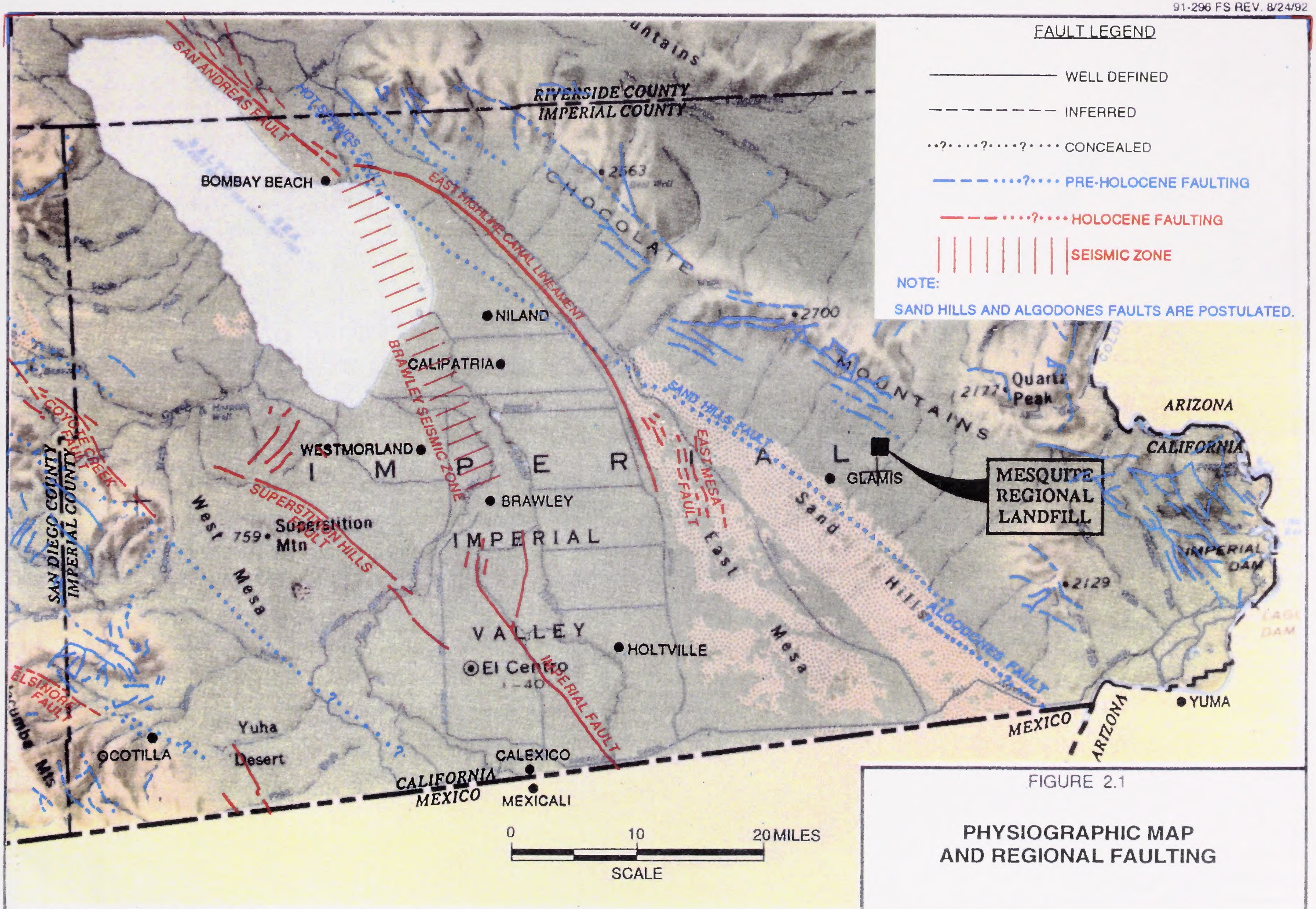
FIGURE 1.2

PEAK ACCELERATION FROM MAXIMUM CREDIBLE EARTHQUAKES

REFERENCE: MAULCHIN AND JONES, 1992. PEAK ACCELERATION FROM MAXIMUM CREDIBLE EARTHQUAKES IN CALIFORNIA

MESQUITE REGIONAL LANDFILL

91-296 FS REV. 8/24/92



REFERENCES: 1. USGS SHADED RELIEF MAP OF CALIFORNIA. DATED 1971.

2. FAULT OVERLAYS MODIFIED AFTER JENNINGS, 1992.

FIGURE 2.1

PHYSIOGRAPHIC MAP
AND REGIONAL FAULTING

MESQUITE REGIONAL LANDFILL

91-296 FS REV 8/16/93

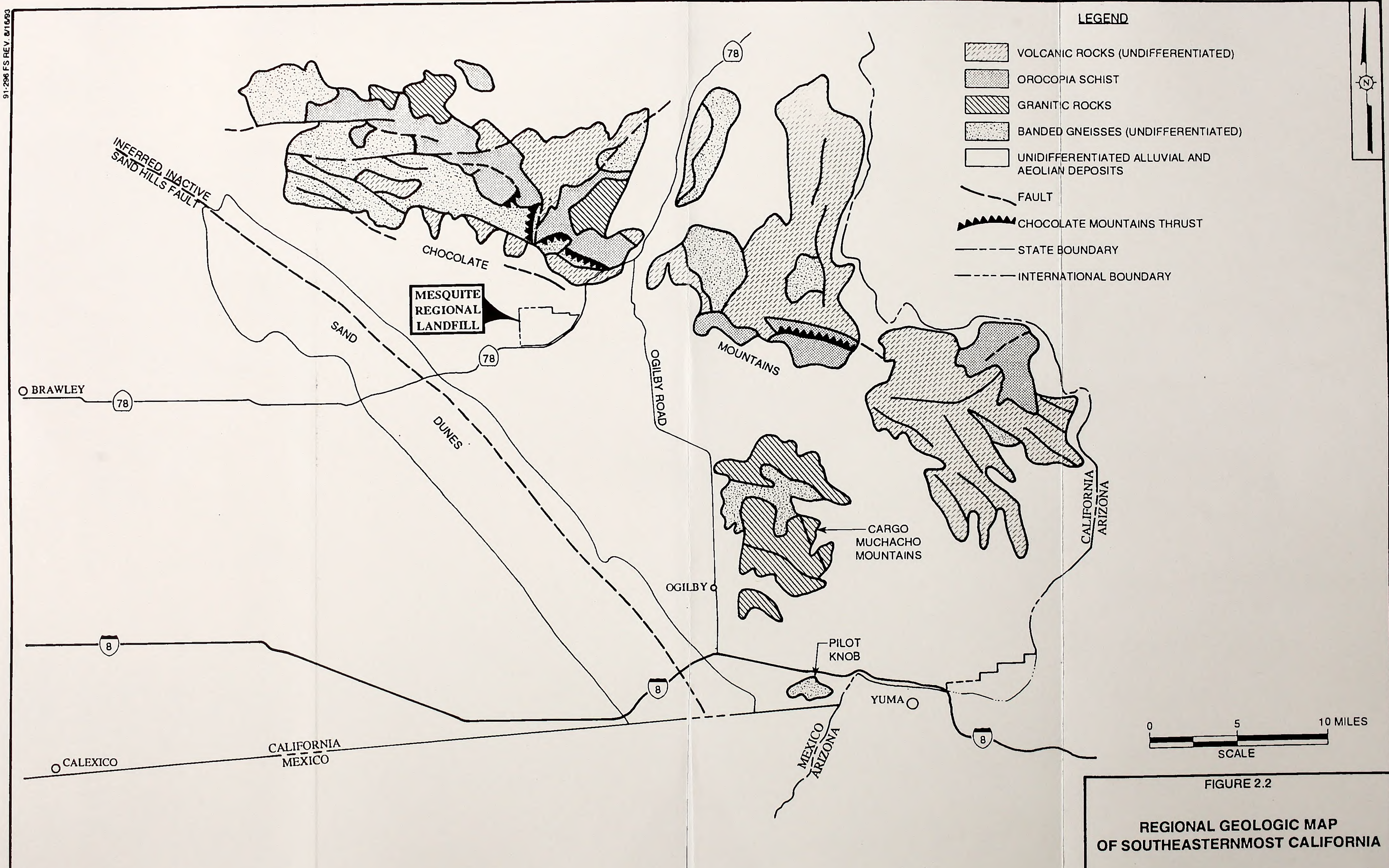


FIGURE 2.2

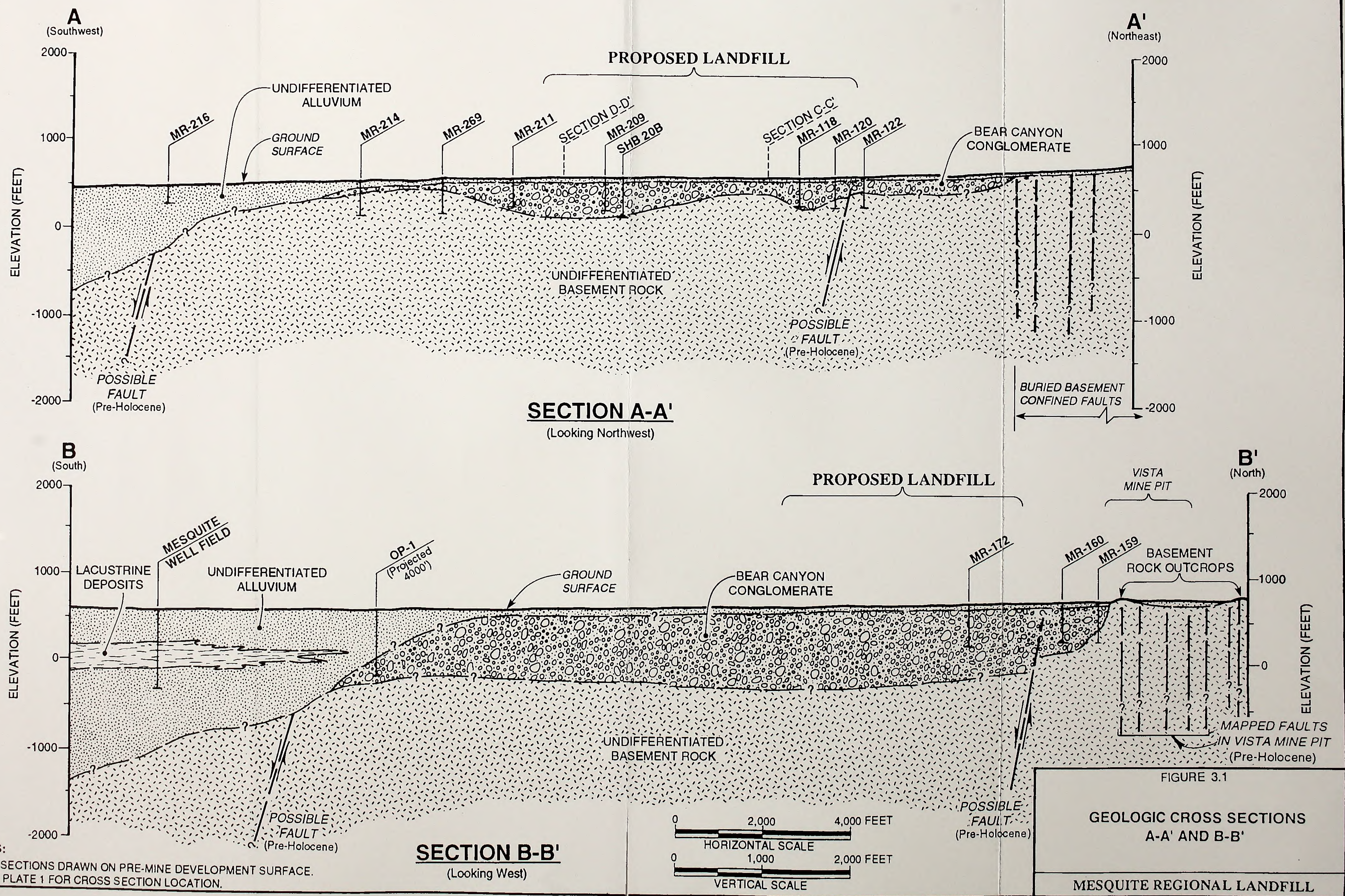
REGIONAL GEOLOGIC MAP OF SOUTHEASTERNMOST CALIFORNIA

MESQUITE REGIONAL LANDFILL

REFERENCES: 1. ADAPTED FROM MORTON, 1977.

2. 1 X 2 DEGREE USGS TOPOGRAPHIC QUAD MAPS OF EL CENTRO AND SALTON SEA, CALIFORNIA.

91-296 FS REV. 8/16/93



NOTES:

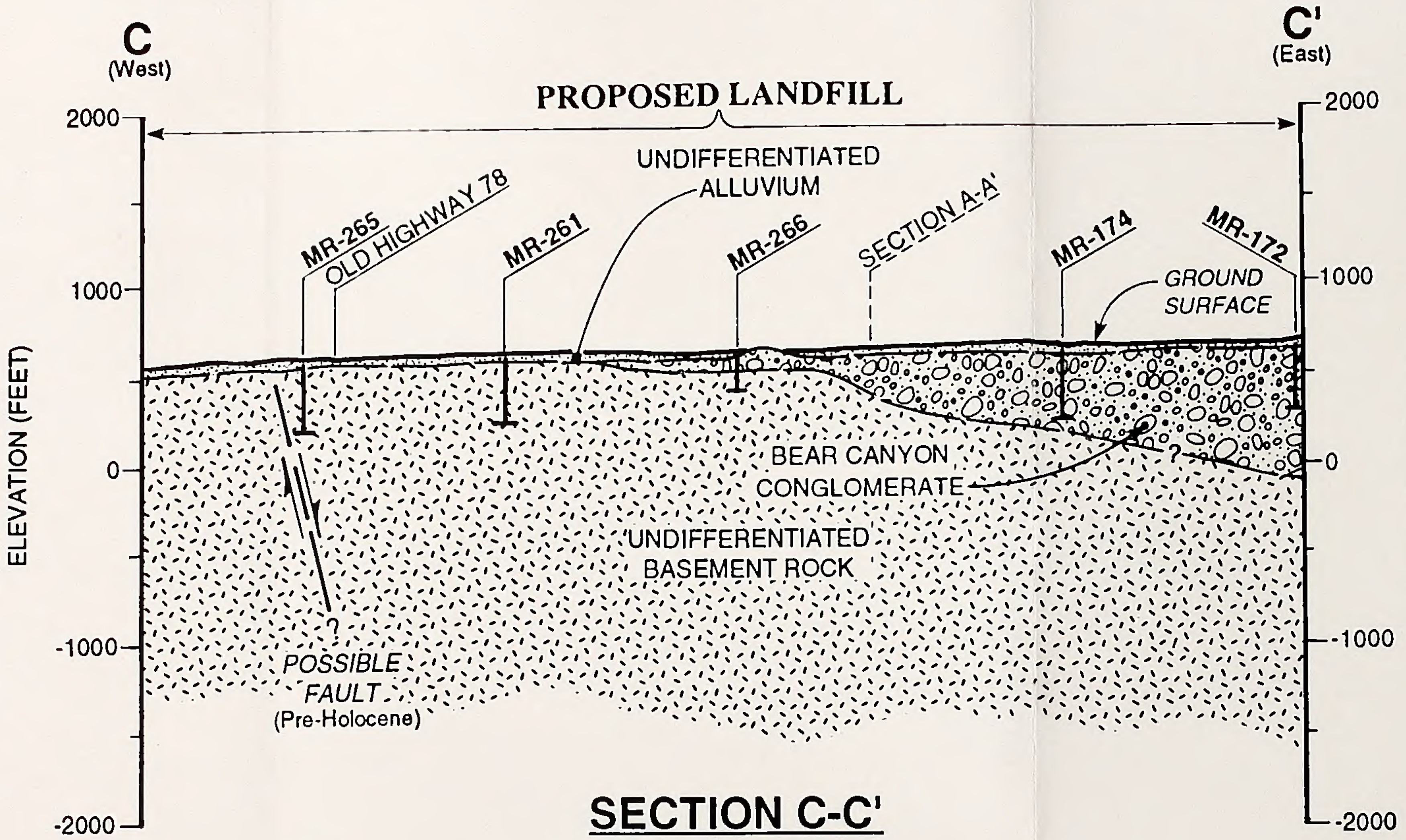
1. ALL SECTIONS DRAWN ON PRE-MINE DEVELOPMENT SURFACE.
2. SEE PLATE 1 FOR CROSS SECTION LOCATION.

FIGURE 3.1

GEOLOGIC CROSS SECTIONS
A-A' AND B-B'

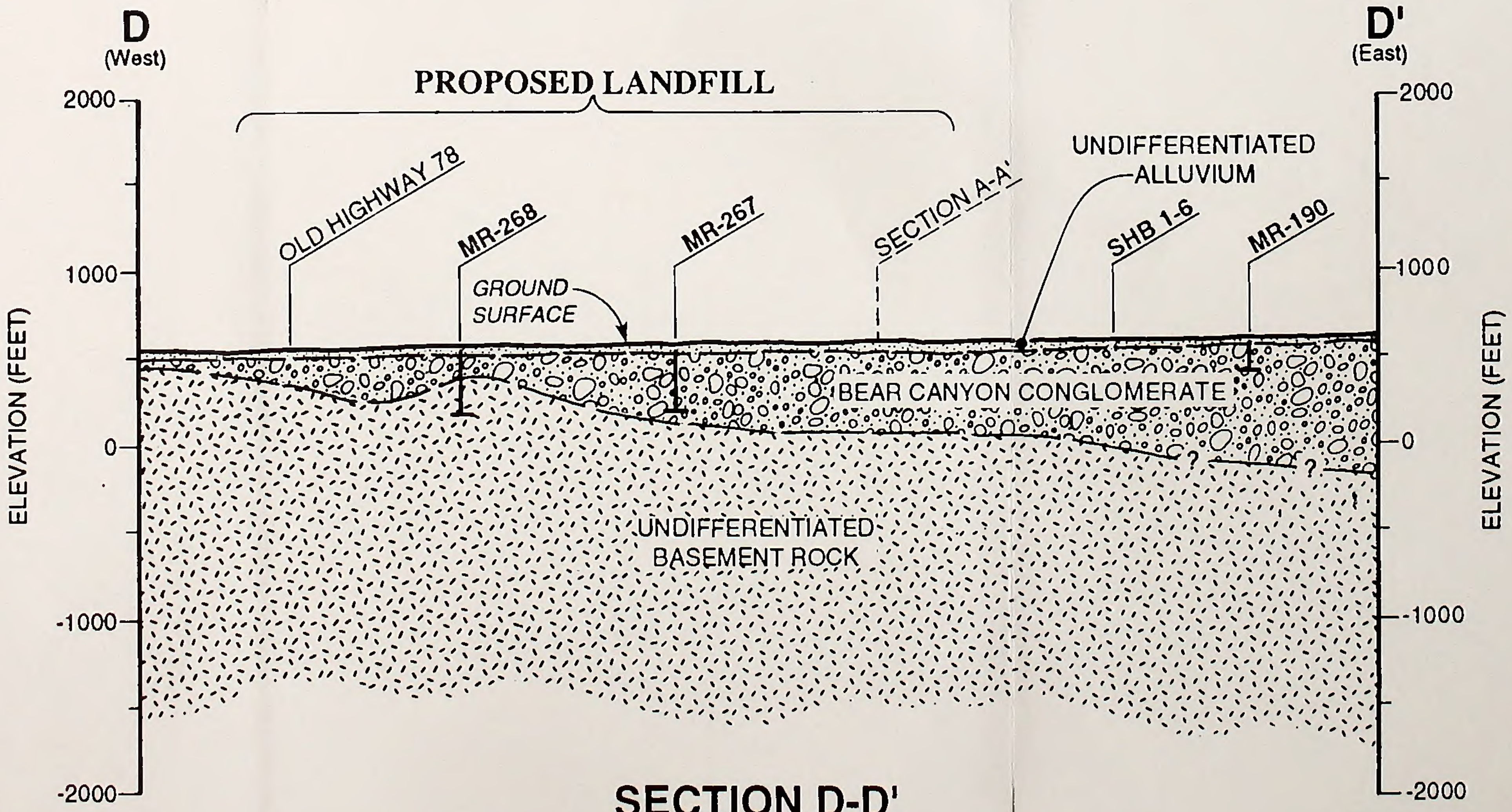
MESQUITE REGIONAL LANDFILL

91-296 FS REV. 8/16/93



SECTION C-C'

(Looking North)



SECTION D-D'

(Looking North)

NOTES:

1. ALL SECTIONS DRAWN ON PRE-MINE DEVELOPMENT SURFACE.
2. SEE PLATE 1 FOR CROSS SECTION LOCATION.

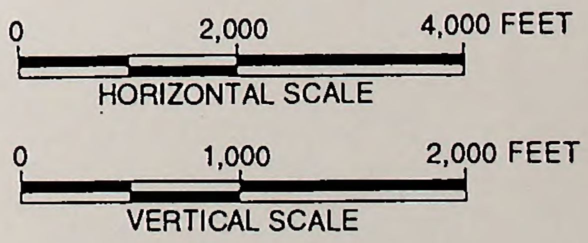


FIGURE 3.2

GEOLOGIC CROSS SECTIONS C-C' AND D-D'

MESQUITE REGIONAL LANDFILL

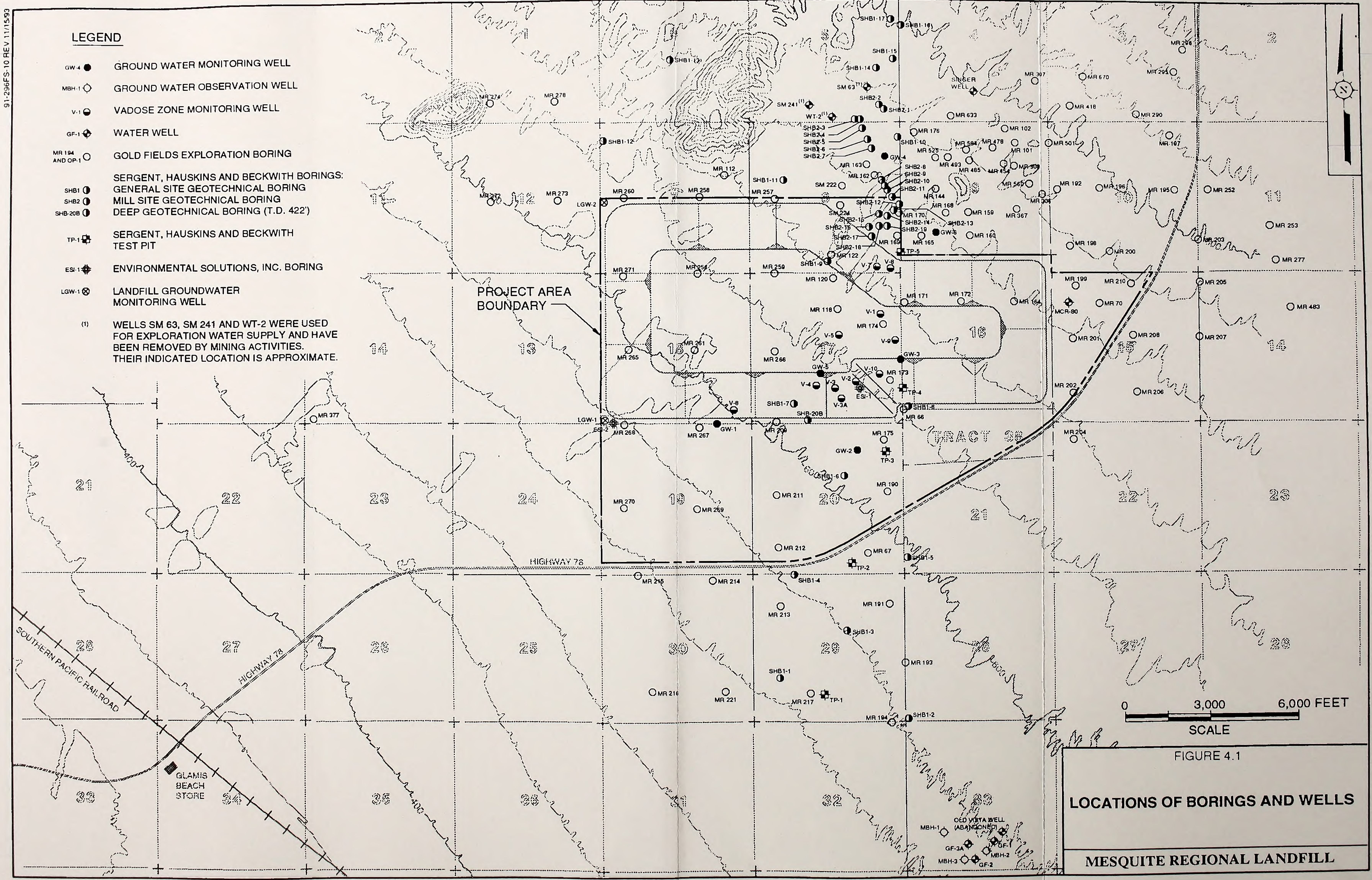
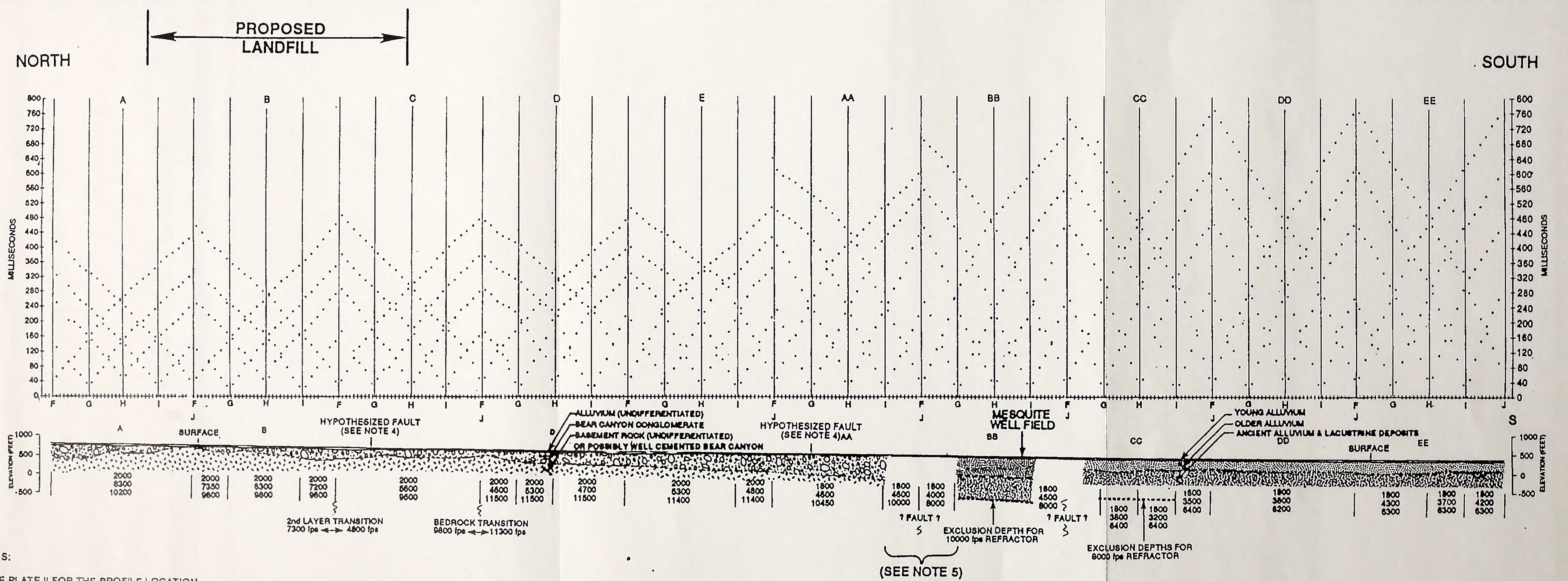


FIGURE 4.1

LOCATIONS OF BORINGS AND WELLS

MESQUITE REGIONAL LANDFILL

91-296 FS REV. 8/16/93



NOTES:

1. SEE PLATE II FOR THE PROFILE LOCATION.
2. VELOCITIES SHOWN ARE IN FEET PER SECOND.
3. TOTAL LINE LENGTH 6.8 MILES, INCLUDING 10-3,800 FT. SPREADS WITH 150 FT. GEOPHONE SPACING AND 5-SHOT POINTS PER SPREAD. SLOPE INTERCEPT AND RECIPROCAL METHODS USED TO CALCULATE DEPTHS OF VELOCITY LAYERS.
4. THIS FAULT HYPOTHESIZED BY ALBERIO DOES NOT HAVE EXPRESSION IN OTHER EXISTING DATA.
5. THIS AREA REPRESENTS THE ZONE WHERE THE PEDIMENT ENDS AND THE ALLUVIUM THICKENS. THE ZONE MAY BE ASSOCIATED WITH THE EAST-WEST TRENDING POSSIBLE FAULT DESCRIBED IN SECTION 4.3.

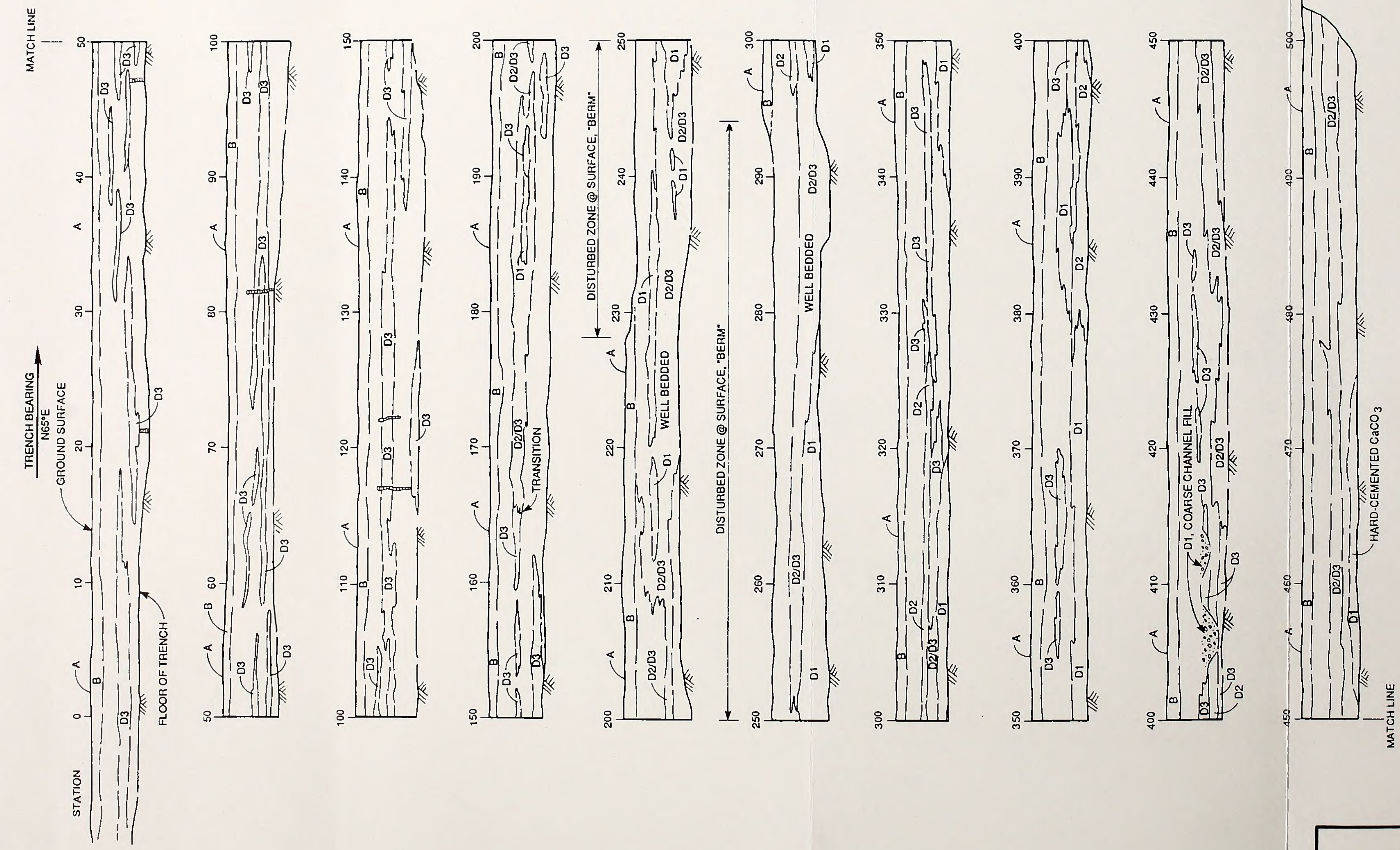
0 2,000 4,000 FEET
SCALE

FIGURE 4.2

SEISMIC REFRACTION PROFILE AND TIME/DISTANCE GRAPH (LOOKING EAST)

MESQUITE REGIONAL LANDFILL

91-296 FS REV. 8/16/93



SUMMARY OF SOIL UNITS
(SEE TABLE 4.1 FOR DETAILED SOIL UNIT EXPLANATION)

A - VESICULAR HORIZON AND PATINA

B - CALCAREOUS ARGILLIC HORIZON

C - CALCAREOUS HORIZON (NODULES)
PARENT MATERIAL

D - FANGLOMERATE:
D1 - SANDY GRAVEL
D2 - GRAVELLY SAND
D3 - SAND
D4 - SILTY SAND
D5 - SILTY SAND WITH ~25% GRAVEL

BITURBATION

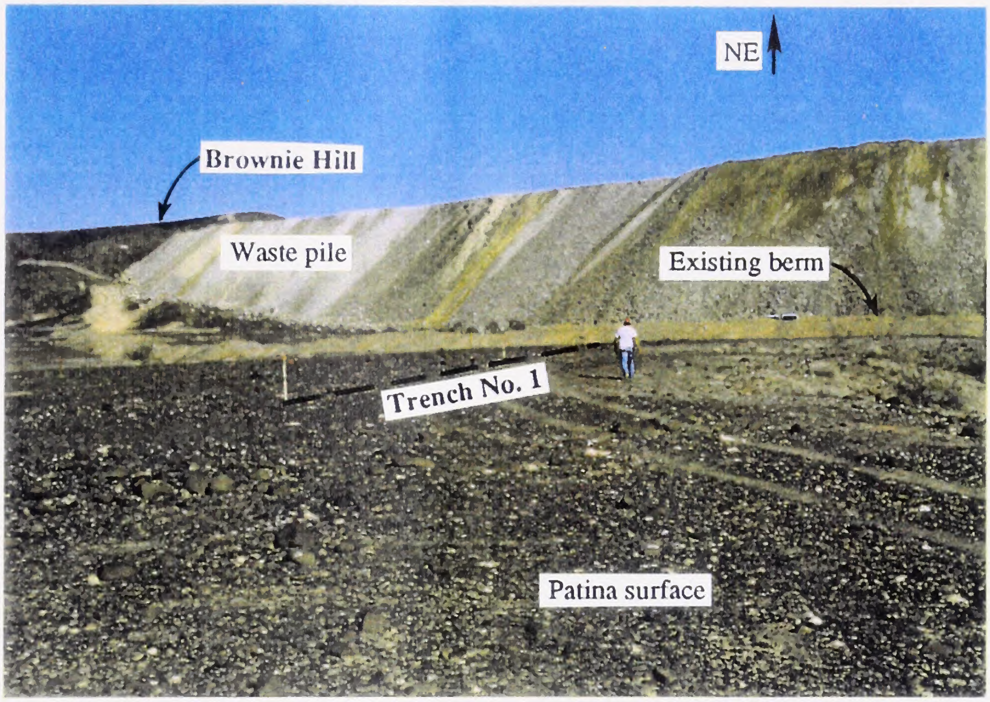
0 8 16 FEET
SCALE
(NO VERTICAL EXAGGERATION)

NOTES:
1. TRENCH LOGGED ON NOVEMBER 12 AND 13, 1991.
2. NORTHWEST SIDE OF TRENCH LOGGED.

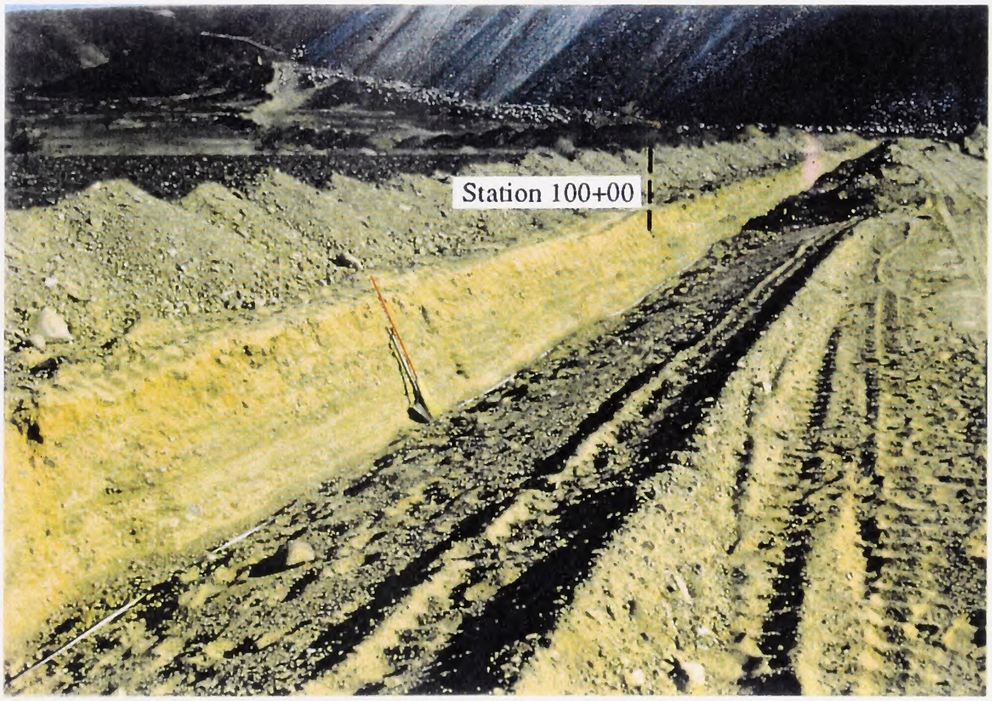
FIGURE 4.3

FAULT INVESTIGATION TRENCH LOG NO. 1

MESQUITE REGIONAL LANDFILL



Trench No. 1, prior to excavtion.



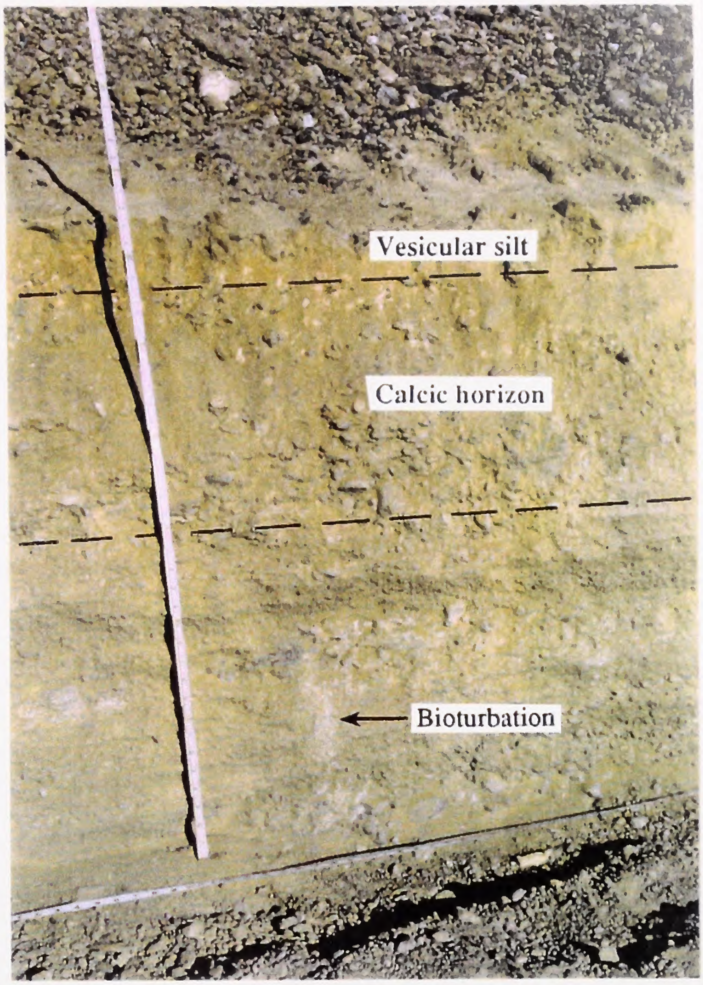
Trench No. 1, looking northeast.

FIGURE 4.4

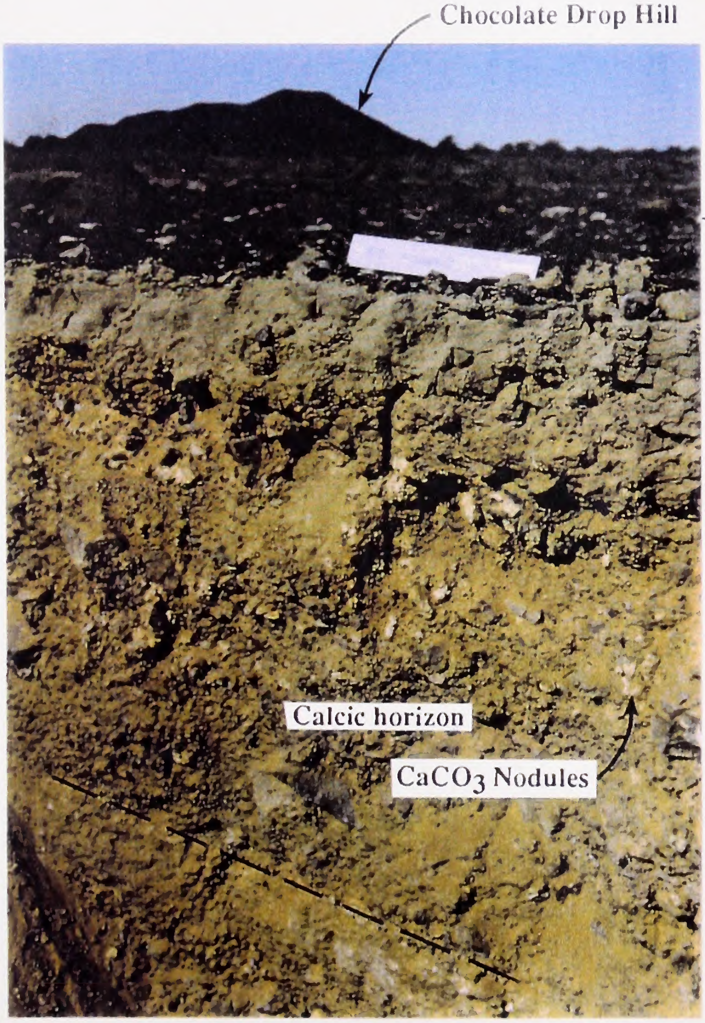
SELECTED FAULT TRENCH PHOTOGRAPHS

MESQUITE REGIONAL LANDFILL

91-296FS REV. 6/1/92



Trench No. 1, looking northwest.



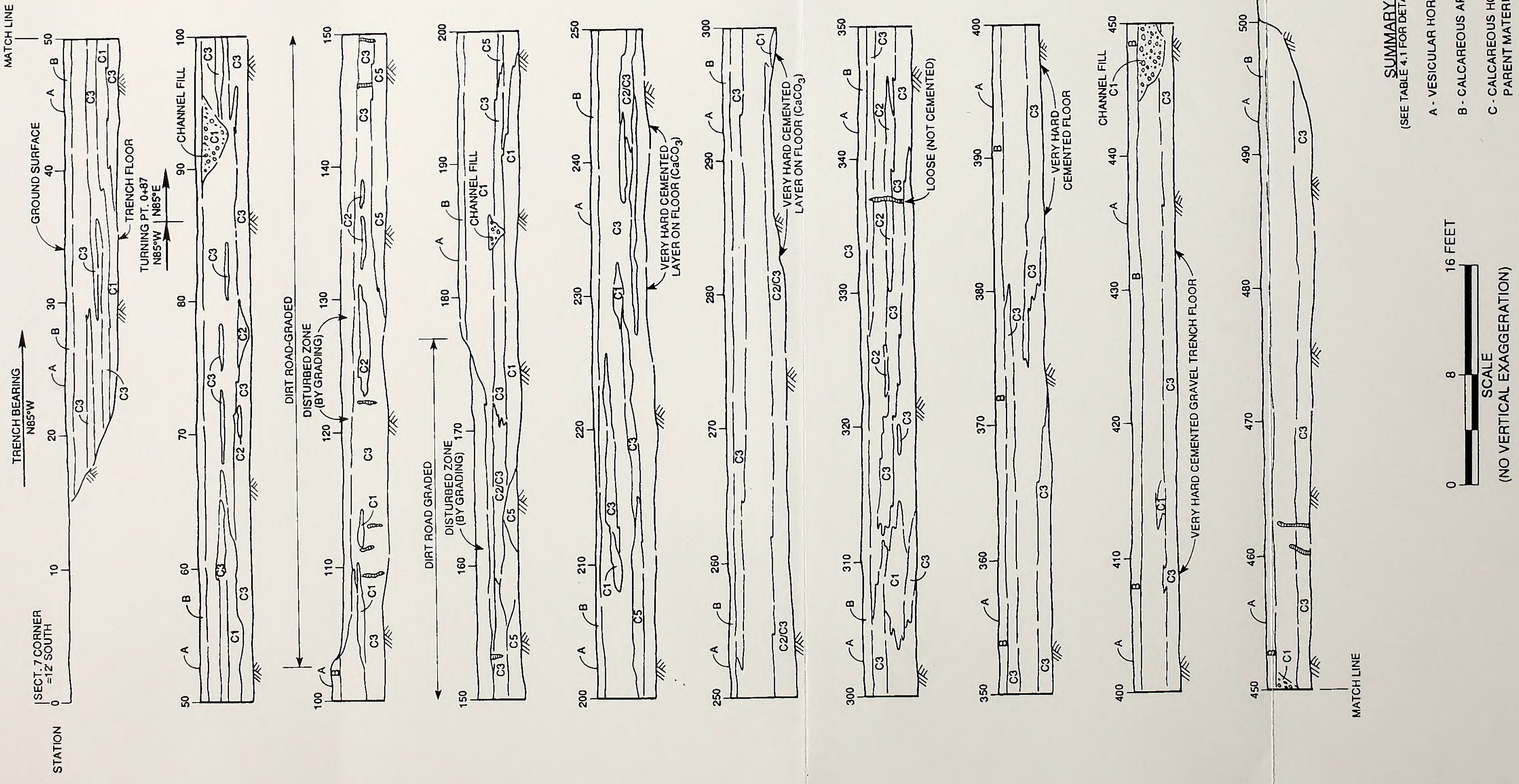
Trench No. 1, looking west.

FIGURE 4.5

SELECTED FAULT TRENCH PHOTOGRAPHS

MESQUITE REGIONAL LANDFILL

91-296 FS REV 8/16/93



SUMMARY OF SOIL UNITS
(SEE TABLE 4.1 FOR DETAILED SOIL UNIT EXPLANATION)

A - VESICULAR HORIZON AND PATINA

B - CALCAREOUS ARGILLIC HORIZON

C - CALCAREOUS HORIZON (NODULES) PARENT MATERIAL

D - FANGLOMERATE:
- D1 - SANDY GRAVEL
- D2 - GRAVELLY SAND
- D3 - SAND
- D4 - SILTY SAND
- D5 - SILTY SAND WITH ~25% GRAVEL

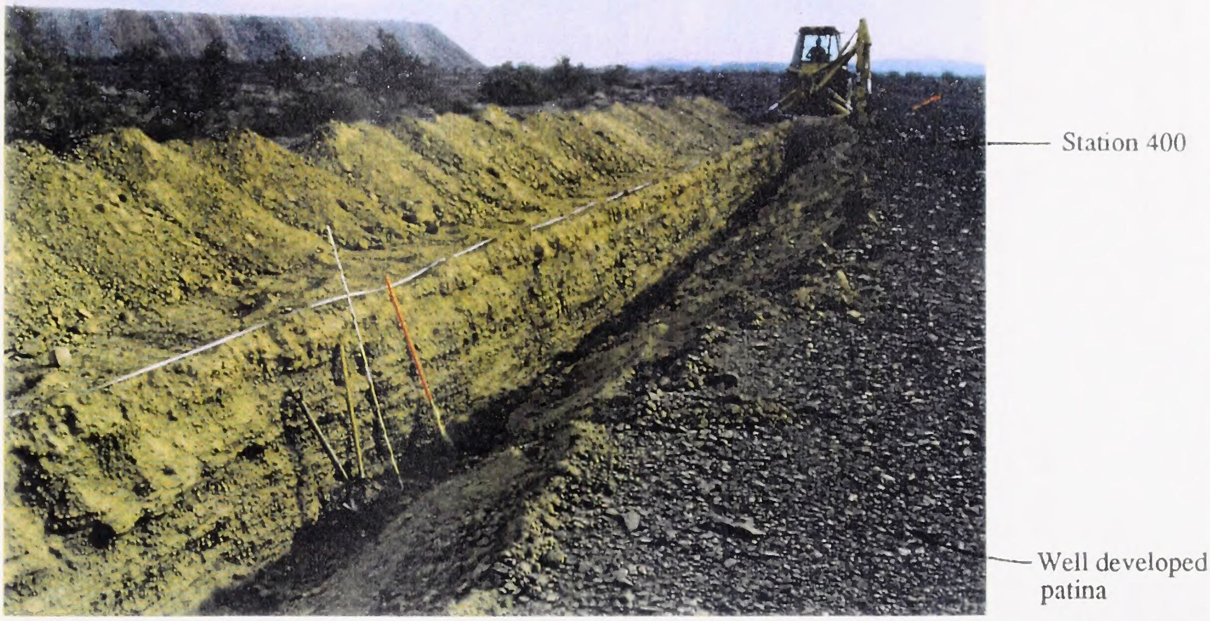
BITURBATION

NOTES:
1. TRENCH LOGGED ON NOVEMBER 12 AND 13, 1991.
2. NORTHWEST SIDE OF TRENCH LOGGED.

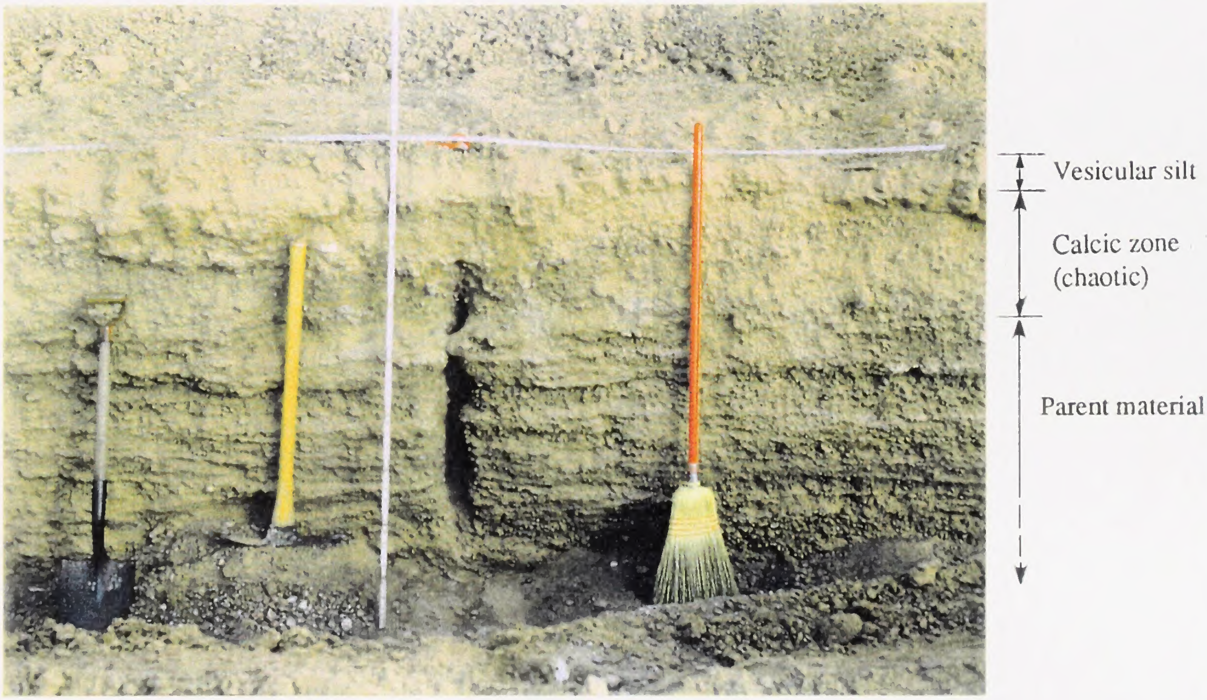
FIGURE 4.6

FAULT INVESTIGATION TRENCH LOG NO. 2

MESQUITE REGIONAL LANDFILL



Trench No. 2, looking eastward. Note well developed bedding on trench wall.

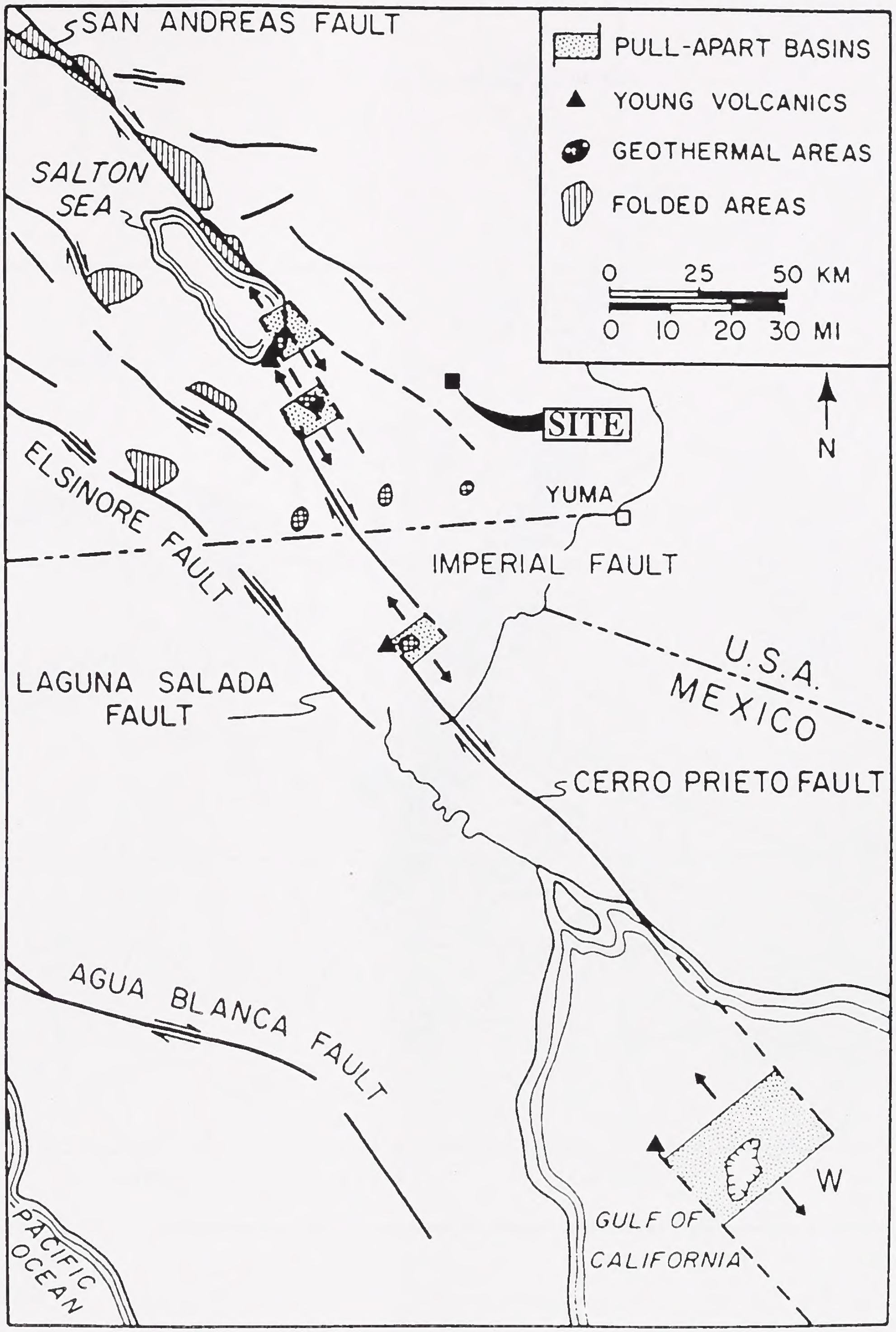


Trench No. 2, typical bioturbation (krotovina).

FIGURE 4.7

SELECTED FAULT TRENCH PHOTOGRAPHS

MESQUITE REGIONAL LANDFILL



POSTULATED SYSTEM OF TRANSFORM FAULTS
AND PULL APART BASINS

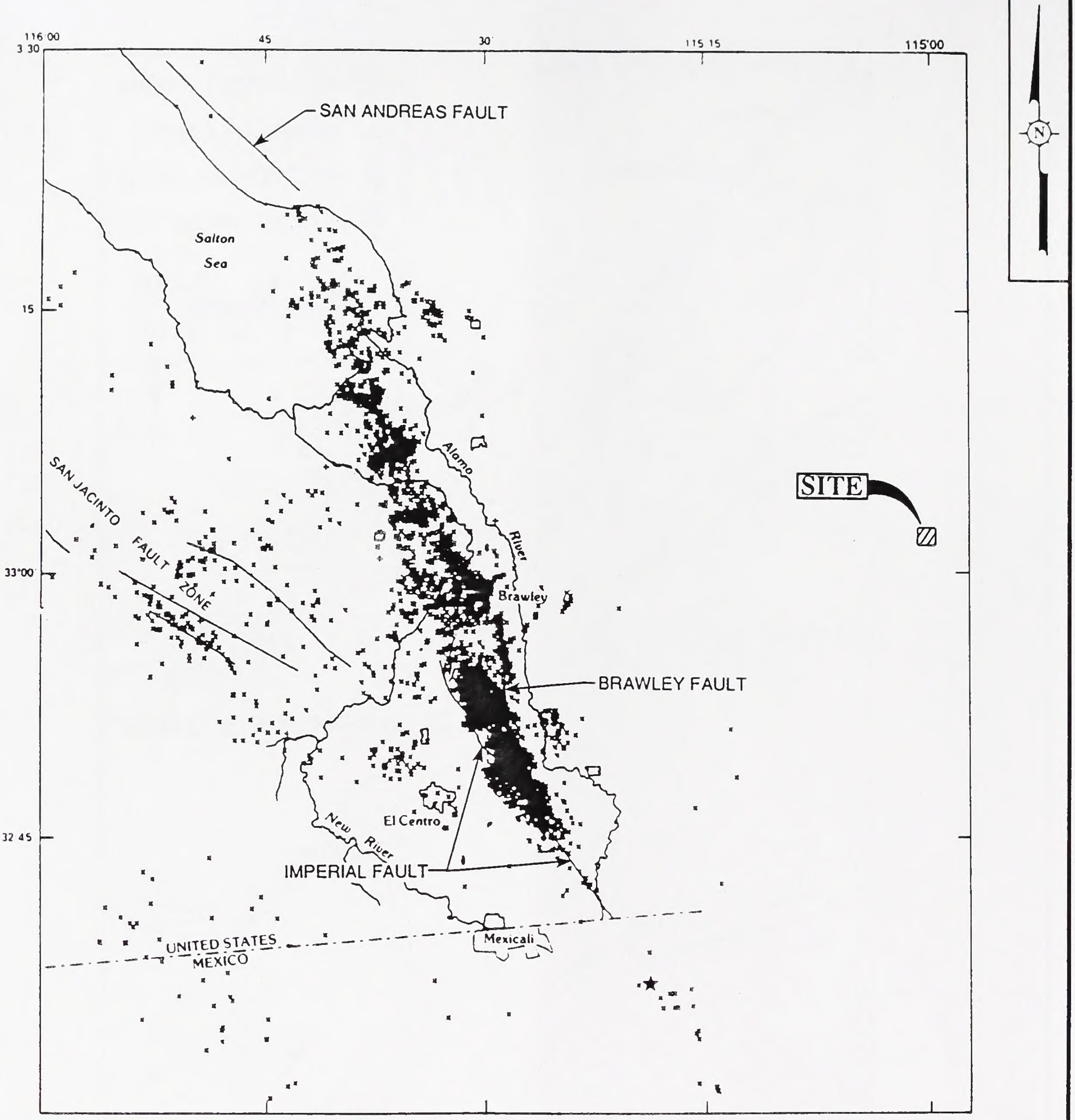
FIGURE 5.1

TECTONIC MODEL - SALTON TROUGH

MESQUITE REGIONAL LANDFILL

REFERENCE:
MODIFIED AFTER: ELDERS, W.A., REX, R.W., MEIDAU, T., ROBINSON, 1972
CRUSTAL SPREADING IN SOUTHERN CALIFORNIA; SCIENCE (1972) PG. 15-24.

91-296 FS REV. 3/9/93



EARTHQUAKE EPICENTERS JUNE 1973 - NOVEMBER 1978

0 10 20 MILES

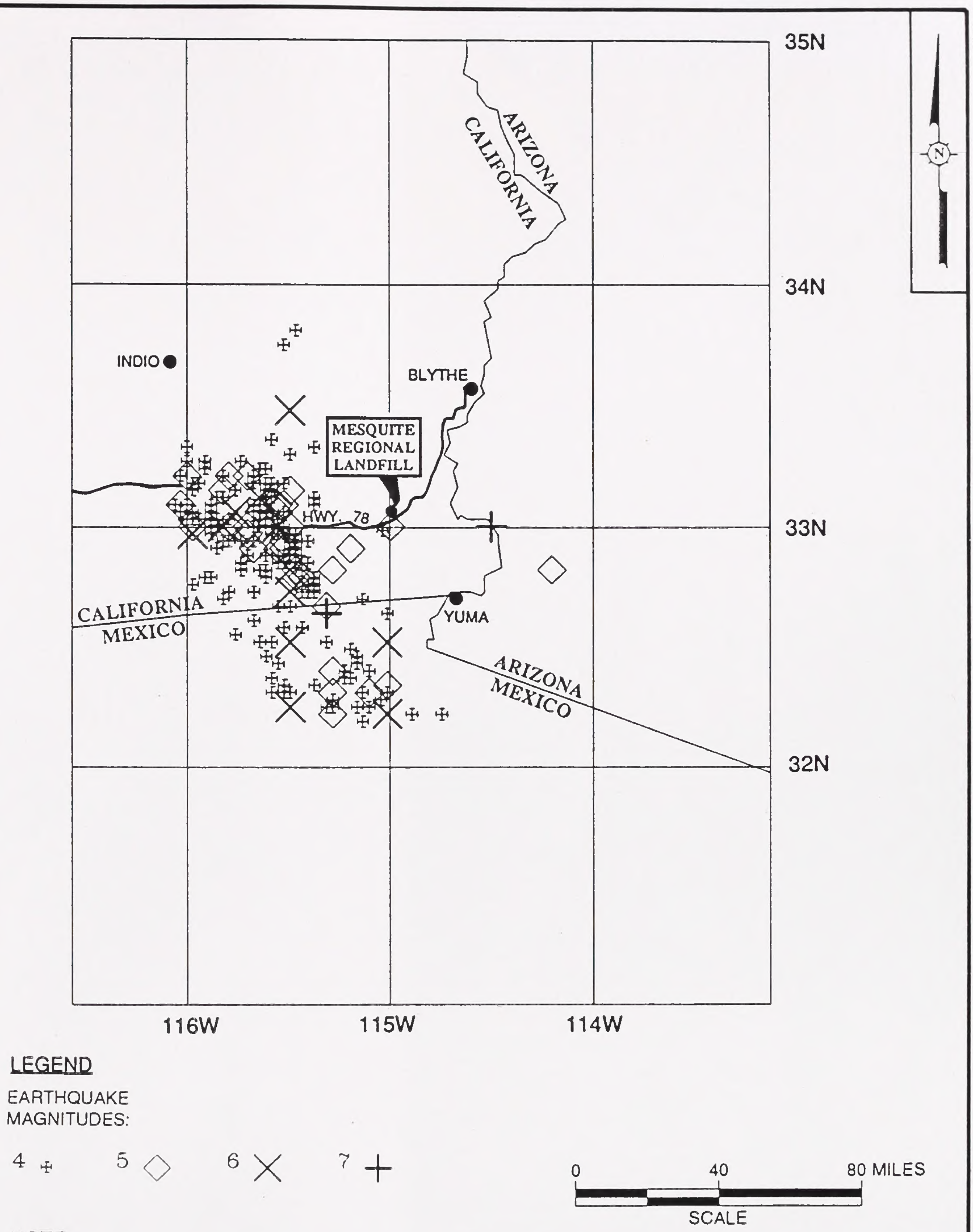
APPROXIMATE SCALE

REFERENCE:
MODIFIED AFTER: DAMIATA, PARK, TIEN-CHAN LEE, 1986

FIGURE 5.2

BRAWLEY SEISMIC ZONE

MESQUITE REGIONAL LANDFILL



NOTE:
EPICENTERS SHOWN OCCURRED BETWEEN 1800 AND 1992 WITH MAGNITUDES GREATER THAN 4.0.

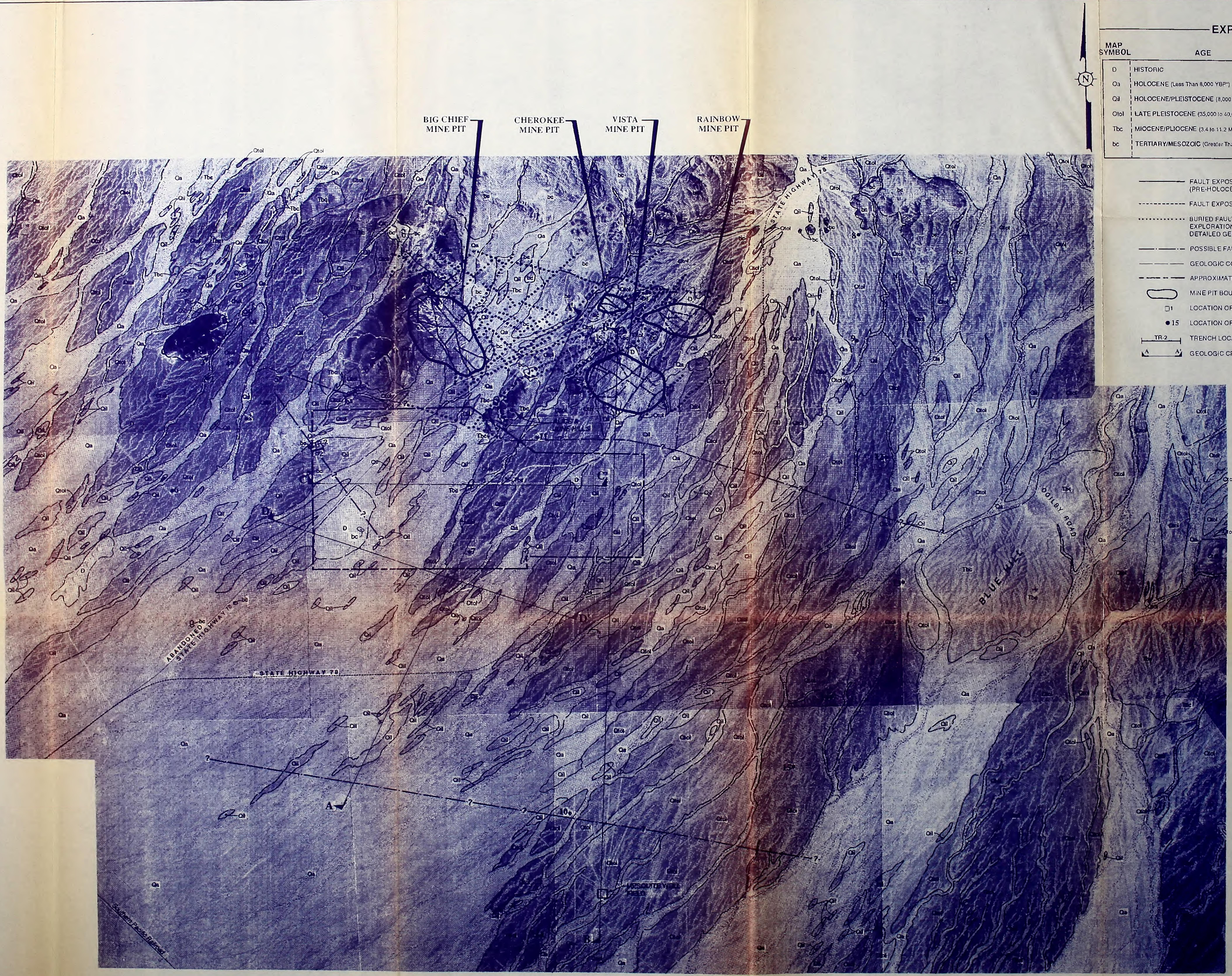
REFERENCE: U.S. GEOLOGICAL SURVEY, NATIONAL EARTHQUAKE INFORMATION CENTER DATA TAKEN FROM THE EARTHQUAKE DATA BASE SYSTEM.

FIGURE 6.1

HISTORIC EPICENTER MAP

MESQUITE REGIONAL LANDFILL

91-290 EISGEO REV. 3/1/93



EXPLANATION

MAP SYMBOL	AGE	GEOLOGIC UNIT
D	HISTORIC	DISTURBED AREA
Qa	HOLOCENE (Less Than 8,000 YBP*)	ACTIVE ALLUVIAL CHANNEL
Qil	HOLOCENE/PLEISTOCENE (8,000 to 17,000 YBP)	INTERMEDIATE ALLUVIAL FAN SURFACE
Qtol	LATE PLEISTOCENE (35,000 to 40,000 YBP)	OLD AGE ALLUVIAL FAN SURFACE
Tbc	MIOCENE/PLIOCENE (3.4 to 11.2 MYBP)	BEAR CANYON CONGLOMERATE
bc	TERTIARY/MESOZOIC (Greater Than 22 MYBP)	UNDIFFERENTIATED BASEMENT ROCK (Metamorphic, Igneous, Volcanic)

———	FAULT EXPOSED ON NATURAL GROUND SURFACE (PRE-HOLOCENE FEATURES)
- - - - - -	FAULT EXPOSED IN MINE PITS (PRE-HOLOCENE FEATURES)
· · · · · · ·	BURIED FAULT TRACES MAPPED BY TOSDAL, ET AL. (1991) BASED ON EXPLORATION DRILLING DATA, MINE PIT EXPOSURES AND DETAILED GEOLOGIC MAPPING
—·—·—	POSSIBLE FAULT - SEE NOTE 1
— — —	GEOLOGIC CONTACT
— - — - —	APPROXIMATE LANDFILL FOOTPRINT
⬭	MINE PIT BOUNDARY
□1	LOCATION OF SOIL-AGE TEST PIT BY SHLEMON (1993)
●15	LOCATION OF SOIL-AGE CONFIRMATION TEST PITS
TR-2	TRENCH LOCATION
A A'	GEOLOGIC CROSS SECTION

NOTES:

1. THESE FEATURES ARE SURFACE PROJECTIONS OF ZONES WHERE THE BURIED BASEMENT ROCK DEEPENS. THIS COULD BE THE RESULT OF PRE-HOLOCENE FAULTING, OR EROSION, OR BOTH.
2. GEOLOGIC UNITS MAPPED BY ENVIRONMENTAL SOLUTIONS, INC.
3. PHOTOGRAPHIC BASE MAP DATED 1982.
4. *YBP = YEARS BEFORE PRESENT; MYBP = MILLION YEARS BEFORE PRESENT.
5. SCALE IS APPROXIMATE DUE TO PHOTOGRAPHIC DISTORTION.

0 2,000 4,000 FEET
APPROXIMATE SCALE

BASEMAP REFERENCE TO BE PROVIDED

PLATE I

SITE GEOLOGIC MAP

ENVIRONMENTAL SOLUTIONS, INC.

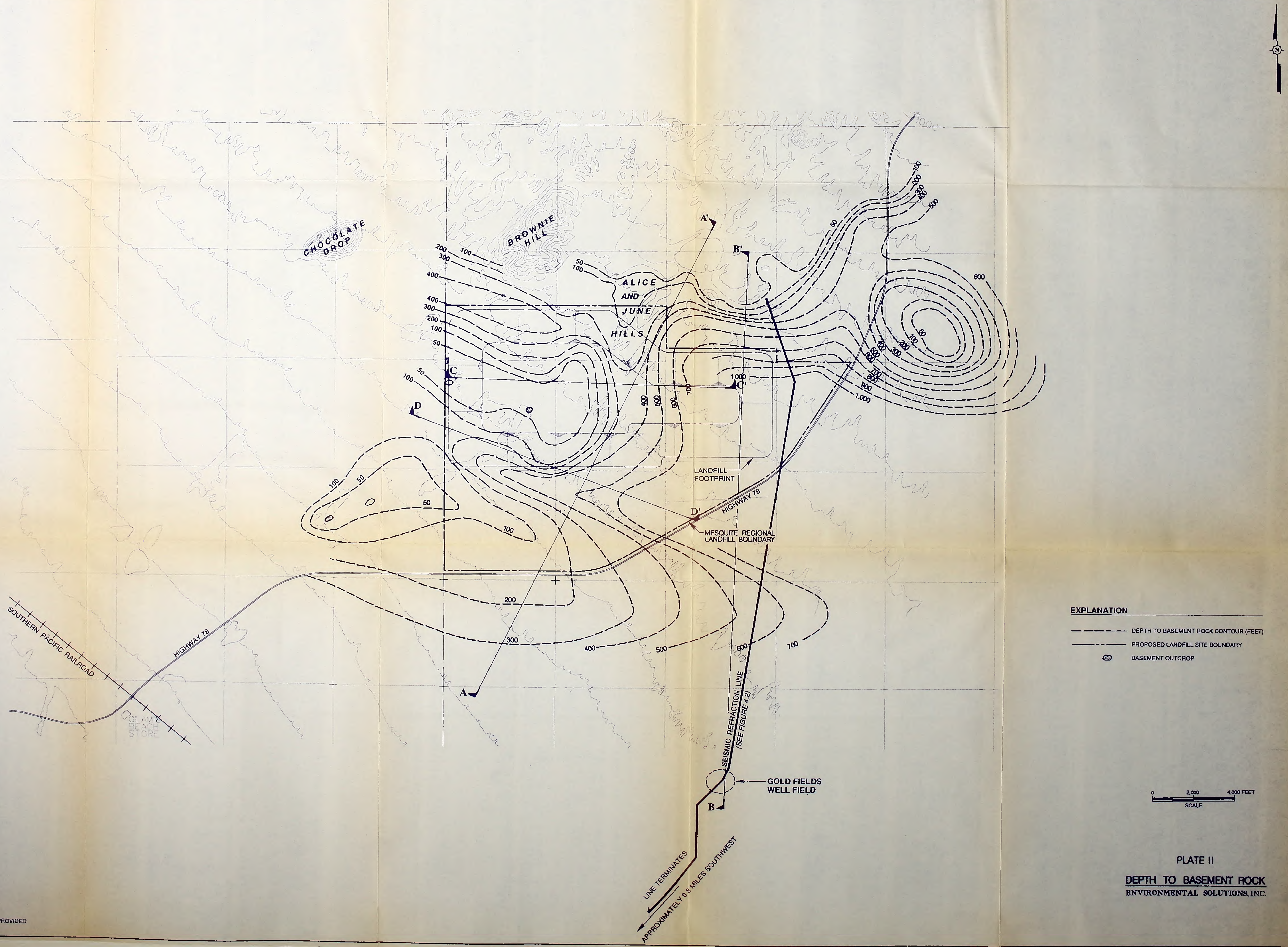

CHOCOLATE DROP
BROWNIE HILL
ALICE AND JUNE HILLS
A'
B'
A
B
C
C'
D
D'
LANDFILL FOOTPRINT
HIGHWAY 78
MESQUITE REGIONAL LANDFILL BOUNDARY
SOUTHERN PACIFIC RAILROAD
SEISMIC REFRACTION LINE (SEE FIGURE 4.2)
GOLD FIELDS WELL FIELD
LINE TERMINATES APPROXIMATELY 0.6 MILES SOUTHWEST
50
100
200
300
400
500
600
700
800
900
1,000
EXPLANATION
DEPTH TO BASEMENT ROCK CONTOUR (FEET)
PROPOSED LANDFILL SITE BOUNDARY
BASEMENT OUTCROP
0
2,000
4,000 FEET
SCALE
N

PLATE II

DEPTH TO BASEMENT ROCK

ENVIRONMENTAL SOLUTIONS, INC.

BASEMAP REFERENCE TO BE PROVIDED

PLATE III

BOUGUER GRAVITY CONTOURS

ENVIRONMENTAL SOLUTIONS, INC.

APPENDIX A

A.1 *SOIL-GEOMORPHIC AGE ASSESSMENTS OF PIEDMONT ALLUVIAL FANS, MESQUITE REGIONAL LANDFILL SITE, IMPERIAL COUNTY, CALIFORNIA*

(SHLEMON, 1993); AND

A.2 *QUATERNARY SOIL - GEOMORPHIC RELATIONSHIPS, SOUTHEASTERN MOJAVE DESERT, CALIFORNIA AND ARIZONA*

(ROY J. SHLEMON, 1980)

A.1 *SOIL-GEOMORPHIC AGE ASSESSMENTS OF PIEDMONT ALLUVIAL FANS, MESQUITE REGIONAL LANDFILL SITE, IMPERIAL COUNTY, CALIFORNIA*

(SHLEMON, 1993); AND

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Geological and Environmental Consultants

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Quaternary Geology
Economic Geomorphology
Soil Stratigraphy
Geoarchaeology

APPENDIX REPORT

SOIL-GEOMORPHIC AGE ASSESSMENTS OF PIEDMONT ALLUVIAL FANS, MESQUITE REGIONAL LANDFILL SITE, IMPERIAL COUNTY, CALIFORNIA

by

Roy J. Shlemon

for

Environmental Solutions, Inc.

January 1993

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Soil Pit 2 5

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Table 1 (Soil Profile Measurement and Description, TP 1 . 9

Table 2 (Soil Profile Measurement and Description, TP 2 . 10

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SOIL-GEOMORPHIC AGE ASSESSMENTS OF PIEDMONT ALLUVIAL FANS, MESQUITE REGIONAL LANDFILL SITE, IMPERIAL COUNTY, CALIFORNIA

INTRODUCTION

This report briefly summarizes the results of a soil-geomorphic reconnaissance assessment to determine the age of two regional landforms at and near the proposed Mesquite Landfill site in Imperial County, California. The reconnaissance was carried out on 22 December 1992, and entailed aerial overview, ground observation, and general measurement of soil profiles described from two backhoe pits, informally designated "Pits 1 and 2," respectively.

General location and geologic maps, as well as the site of the two soil pits, are given in an accompanying document "Fault and Seismicity in the Vicinity of the Mesquite Regional Landfill" prepared by Environmental Solutions, Inc. (ESI). The conclusions of this assessment were previously reviewed with ESI consultants, but are here restated as more formal documentation. Logistical support and technical discussions were kindly provided by Consulting Engineering Geologist, M. Payne.

SOIL-GEOMORPHIC BACKGROUND

The approximate age of many desert landforms and underlying sediments are readily deduced by assessing the relative development of soil (pedogenic) profiles. The technique is increasingly used in the Mojave and Sonoran Deserts of California in order to assess fault activity, to determine the relative stability of geomorphic surfaces, and to reconstruct Quaternary paleo-environments (see, for example, summaries and case studies in Cooke and Warren, 1973; Shlemon, 1978, 1985; Christenson and Purcell, 1985; Machette, 1985; Ponti, 1985; and McFadden, 1988).

Four principal pedogenic characteristics typify increasingly older suites of desert soils: (1) relative development of desert pavement and clast patina; (2) presence and increasing thickness of a vesicular horizon (Av); (3) the thickness, reddening and abundance of illuvial clay films in argillic horizons; and (4) the number, depth and relative morphology of carbonate rinds and nodules in calcic horizons.

In general, middle and late Holocene geomorphic surfaces (floodplains, low fluvial terraces and distal fans) are still active, characterized by on-going sedimentation, the local presence of bar and channel morphology, and undeveloped (A/C) soil profiles (Entisols). In contrast, early Holocene and middle to late Pleistocene surfaces, particularly piedmont fans, are typified by moderately- to well-developed desert pavement and patina, by vesicular and argillic horizons, and often by multiple calcic horizons (Haplargids). Pre-middle Pleistocene face surfaces are often "cut off" from adjacent mountain fronts, are several to tens of feet above modern floodplains, are normally characterized by strongly-development pavement and high reflectance (albedo), and are replete with thick, strongly-developed argillic and multiple calcic horizons (Paleargids). Frequently, calcic horizon depth reaches several feet on old fan surfaces, far below the modern carbonate wetting front. Such carbonate depths often indicate that the soils, and hence the geomorphic surface on which they are forming, have been subject to one or more pluvial environments of the past (Arkley, 1963; Shlemon, 1978; McFadden and Tinsley, 1985). Further, in addition to reflecting the passage of time and the impact of climate and vegetation change, desert landforms and soils are influenced by eolian dust influx, and by the grain size and lithology of sediment parent material. Granitic rocks, for example, usually weather to gruss, and thus produce only weak desert pavement. In contrast, metamorphic, basaltic and other mafic-rich rocks give rise to moderately- to strongly-developed pavements and patina in a relatively short time, typical of those in the Mesquite Landfill area. Of importance, too, is that soil profiles date the relative stability of geomorphic surfaces, and thus inherently provide a minimum age for the underlying sediments (parent material).

MESQUITE AREA LANDFORMS AND SOILS

Soil Pit 1

Soil Pit 1 was emplaced across a medial segment of a middle-level geomorphic piedmont fan surface, adjacent to a previously-excavated Trench (ESI, this volume). The fan sediments are mainly derived from adjacent bedrock outliers of meta-igneous and basaltic rocks. As a result, the Soil Pit 1 fan bears a moderately- to strongly-developed desert pavement.

More illustrative of relative soil age is the presence of an approximately 2-in thick vesicular horizon (Av) and underlying calcareous argillic horizons (B2tk; Table 1). The argillic horizon is yellowish red, and bears few to common illuvial clay films on subangular blocky ped faces. A few fine carbonate nodules occur to depths of about 1.4 ft, well below the present depth of carbonate leaching, thus indicating that the Pit 1 surface has been subject to at least one previous soil "pluvial" epoch. The calcic horizon morphology, combined with the presence of the moderately-developed argillic horizon, suggest that the Pit 1 soil has probably been forming for about the last 35,000 to 40,000 years, likely initiated during a time of relative landscape stability associated with stage 3 of the marine oxygen-isotope chronology (Shackleton and Opdyke, 1976; Shlemon, 1985). The underlying angular gravelly parent material is inherently older, perhaps laid down, at a minimum, about 60,000 to 70,000 yrs ago (isotope stage 4).

Soil Pit 2

Soil Pit 21 was sited adjacent to a geologically-logged trench (ESI, this volume) on a slightly-dissected alluvial fan surface. The desert pavement is moderately-developed with most clasts derived from outcrops of adjacent basaltic bedrock.

Only a 1-inch thick vesicular horizon (Av) underlies the desert pavement in this soil. The argillic horizon is also incipient (Btjk), relatively thin and typified by a few, thin clay films lining root tubules (Table 2). In contrast to Soil 1, only one calcic horizon is apparent, superimposed on the argillic horizon. Some disseminated carbonates do occur in the upper parent material (C1 horizon), suggesting that the soil was possibly subject to a former more "pluvial" environment, possibly in latest Pleistocene or early Holocene time.

Geomorphically, the Soil 2 surface lies but a few feet above adjacent bar and channel deposits, suggesting that portions of this surface have or are being subject to long-recurrence overtopping. In general, the presence of an incipient calcareous argillic horizon (Btjk), and the lack of clear multiple calcic horizons indicate that the Pit 2 soil may be as young as about 8,000 years old. However, the weak disseminated carbonates in the upper parent material suggest that perhaps the soil began forming as much as about 17,000 years ago. Carbonates are still being added to the soil profile, ostensibly by influx of eolian dust. Accordingly, in view of profile characteristics observed in Soil Pit 2, the age of the soil -- and hence a minimum age for the underlying fanglomerate -- is judged to be about 8,000 to 17,000 years old, likely no older than stage 2 of the oxygen-isotope stage chronology. However, more definitive assessments may well be obtained by possible additional and more detailed soil profile measurements and descriptions taken elsewhere on the Soil Pit 2 surface.

SUMMARY AND CONCLUSIONS

The relative age of two regional piedmont alluvial fans in the Mesquite Landfill area is assessed by geomorphic and relative soil profile development. Soil Pit 1 exposes a moderately-developed profile, replete with vesicular, argillic and multiple calcic horizons. Such profiles have likely been subject to at least one former soil pluvial epoch. Accordingly, the Pit 1 soil likely began forming during a time of relative landscape stability (isotope stage 3) about 35,000 to 40,000 years ago.

In contrast, the Pit 2 soil is less well developed. Only a thin vesicular and incipient argillic horizon are present. Some carbonates occur in the upper parent material, but are too disseminated to constitute a separate calcic horizon indicative of former soil pluvial conditions and hence soil antiquity. The Pit 2 soil is therefore judged to be about 8,000 to 17,000 years old.

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TABLE 1

GENERAL SOIL PROFILE MEASUREMENT AND DESCRIPTION, TEST PIT 1, MESQUITE REGIONAL LANDFILL SITE

Geomorphic setting: middle-level geomorphic surface; medial segments, piedmont alluvial fans; moderately to strongly-developed desert pavement; parent material mainly locally-derived basalt with approximately five percent quartz fragments; high albedo.

HORIZON	DEPTH (ft)	DESCRIPTION
Av-B1	0.0-0.2	Yellowish red (5YR 4/6) to light brown (7.5YR 6/4) silty clay loam; weak moderate angular blocky structure; slightly hard, firm, slightly sticky and slightly plastic; effervescent; abrupt wavy boundary
B2tk	0.2-0.8	Yellowish red (5YR 5/8) to yellowish red (5YR 5/6) when moist; gravely silty clay; massive to weak, very fine subangular blocky structure; soft, friable, slightly sticky and slightly plastic; violently effervescent; common, carbonate nodules, rounded to 0.5 inches diameter; few to common clay films lining ped faces and filling root tubules; very angular clasts to 3 inches diameter near base; gradual wavy boundary
B3-C1	0.8-1.4	Strong brown (7.5YR 5/8) dry and moist; gravely silty loam; massive structure; slightly hard, friable, non-sticky and non-plastic; effervescent; few fine carbonate nodules; very angular clasts to 3 inches diameter (fanglomerate); gradual wavy boundary
C2	1.4-2.5+	Very angular gravely clasts to 3 inches diameter; parent material; locally derived basaltic fanglomerate
Estimated soil age 35,000 - 40,000 years for fan surface; based on presence of moderately-developed argillic horizon, presence of disseminated Stage II carbonates in Btk horizon; parent material estimated age 60,000 - 70,000 years		

TABLE 2

GENERAL SOIL PROFILE MEASUREMENT AND DESCRIPTION, TEST PIT 2, MESQUITE REGIONAL LANDFILL SITE

Geomorphic setting: slightly-dissected fan surface; moderately to strongly developed desert pavement; medial piedmont fan segments; high albedo with 90-95 percent of angular clasts derived from local basaltic sources.

HORIZON	DEPTH (ft)	DESCRIPTION
Av	0.0-0.1	Pale brown (10YR 6/3) silty clay; weak, very fine subangular blocky structure; hard, firm, slightly sticky and non-plastic; abrupt wavy boundary
Btjk	0.1-0.4	Yellowish red (5YR 4/6) silty clay; moderate medium angular blocky structure; very hard, very firm, slightly sticky and slightly plastic; effervescent; very few, thin clay films lining root tubules; few very fine disseminated calcium carbonates throughout horizon; approximately 20 percent fine angular gravels; gradual wavy boundary
C1	0.4-1.2	Reddish yellow (5YR 6/6) very fine gravely silty clay; massive structure; hard, firm, non-sticky and non-plastic, effervescent; Stage I disseminated carbonate nodules throughout matrix; abrupt wavy boundary
C2	1.2-2.2+	Parent material: very angular gravels to three inches diameter; primarily basaltic fanglomerates, locally derived
Estimated soil age approximately 8,000 - 17,000 years; based on presence of incipient argillic horizon (Btjk) and moderately-developed, undissected desert pavement		

A.2 *QUATERNARY SOIL - GEOMORPHIC RELATIONSHIPS, SOUTHEASTERN MOJAVE DESERT, CALIFORNIA AND ARIZONA*

(ROY J. SHLEMON, 1980)

QUATERNARY SOIL - GEOMORPHIC RELATIONSHIPS, SOUTHEASTERN MOJAVE DESERT, CALIFORNIA AND ARIZONA

Roy J. Shlemon

P.O. Box 3066 Newport Beach, CA 92663

INTRODUCTION

The geological literature abounds with studies of landform evolution and geomorphic processes operative in warm deserts. This is particularly true for the Mojave Desert of southeastern California and western Arizona (Cooke and Warren, 1973). Unfortunately, however, the absolute ages of most desert landforms remain enigmatic, for few deposits older than about Holocene age are susceptible to dating by radiocarbon or other radiometric techniques. Thus most landforms and underlying sediments by necessity are usually deemed "early," "middle," or "late" Pleistocene in age.

With few exceptions, the age of desert soils is similarly unknown. In general, most profiles are Aridisols, some certainly developing under environments of the past, as indicated by relative profile development and certain morphological characteristics, but their geological age is yet speculative.

Most information about desert profiles in the southwestern United States has come mainly from the pioneering soil-geomorphic studies in southern New Mexico, primarily by Ruhe (1967), Gile (1966, 1968, 1974), Gile and Hawley (1966, 1968), Gile et al. (1965, 1966, 1970) and Smith and Buol (1968). For the Mojave Desert in general, desert soil morphology was described early by Nikiforoff (1937), and Buol and Yessilsoy (1964); and most recently, as related to Quaternary investigations in Nevada and Arizona, by Nettleton et al. (1975).

Unfortunately, few data have been available to assess the age of alluvial landforms and related soils for that portion of the southeastern Mojave Desert, California and Arizona bordering the lower Colorado River between, approximately, the Whipple Mountains on the north and Yuma, Arizona, on the south (Figure 1). Now, however, recent investigations for nuclear power plant siting have shed much light on desert soil-geomorphic relationships. These studies, following requirements of the Nuclear Regulatory Commission (NRC), have sought to date

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*This paper is modified from Quaternary Soils (W. C. Mahaney, ed.), Geo Abstracts, Pub., University of East Anglia, Norwich, England, p. 187-207. The original abstract, several illustrations and reference thereto have been deleted in the present paper.

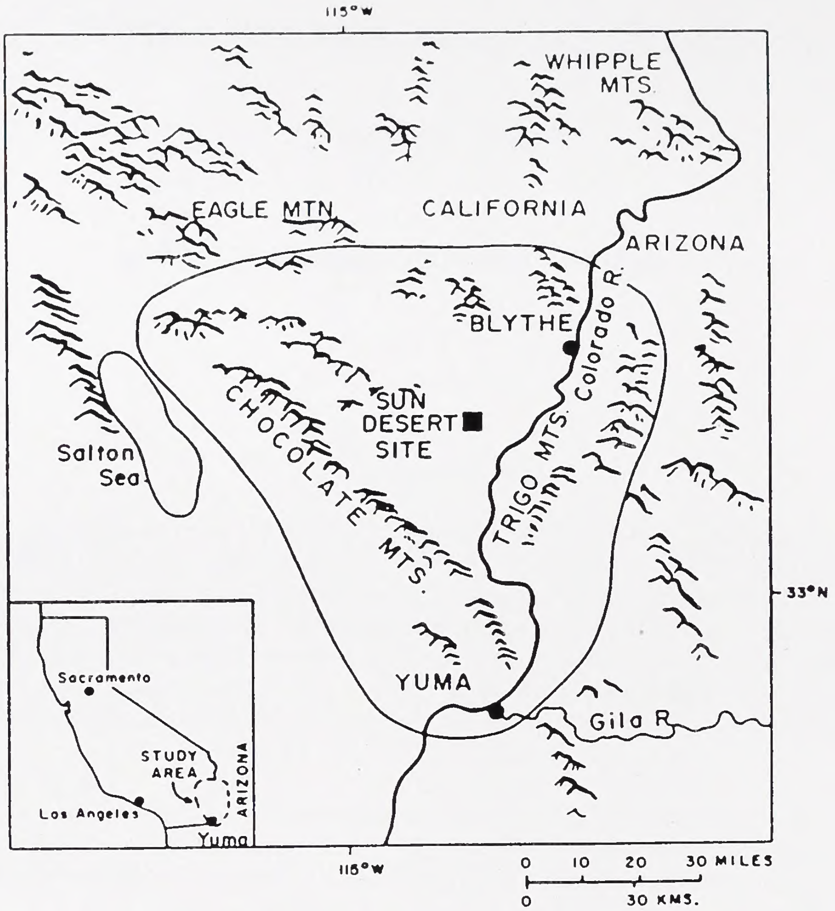

Figure 1 Reconnaissance area, soil-geomorphic investigations, southeastern Mojave Desert, California and Arizona.

Quaternary sediments and related geomorphic surfaces over an approximately 10,000 sq km area of the southeastern Mojave Desert in order to ascertain the last movement of any fault which might be identified in geological mapping. Most of the studies have not yet been formally published in well-known geological or pedological journals. They are, however, available as appendices in various Early Site Review Reports (ESRR), and Preliminary Safety Analysis Reports (PSAR); see, for example, Bull (1974a; 1974b), Ku (1975), Kukla and Opdyke (1973), Lee and Bell (1975), Murray et al. (1976), and Shlemon and Purcell (1976). These nuclear site-related studies have now yielded new information regarding the Quaternary stratigraphy, soils, and landforms in this portion of the Mojave Desert, their relative ages and, in some cases, their "absolute" ages based on radiometric and magnetic dating.

This paper therefore summarizes key aspects of these soil-geomorphic studies in the southeastern Mojave Desert, California and Arizona. Particularly emphasized are data from siting studies for the Sundesert Nuclear Generating Station near Blythe, California (San Diego Gas and Electric Co., 1976). Pointed out are the broad alluvial sequences in this area and geomorphic criteria useful for their separation in reconnaissance, and the approximate ages of related geomorphic surfaces and the soils forming upon them. Reviewed briefly also is the probable rate of Aridisol formation in this area compared with the well-studied soils on similar flights geomorphic surfaces in the semi-arid terrain of southern New Mexico (Gile, 1974, 1977; Gile and Hawley, 1966, 1968; Gile et al., 1966, 1970).

GEOMORPHIC SETTING

The area studied is approximately triangular-shaped, covering some 10,000 sq km in California and Arizona, centered around the proposed Sundesert Nuclear Generating Station, about 32 km southwest of Blythe, California (Figure 1). Fifteen major mountain ranges are encompassed within the study area. The entire region is within the Mojave Desert, a subdivision of the Sonoran physiographic province.

A great variety of lithologies make up the core of the several mountain systems in this region. These rocks, reflected in the Quaternary alluvium, range in age from Mesozoic granitic intrusives to diverse pre-Cretaceous metamorphic and metasediments with some younger volcanics. These contrasting lithologies weather differently, develop distinctive surfaces, and thus affect the geometry, morphology, and photographic tonal expression of Quaternary landforms and soils identified in these studies.

The climate, reflected in the landforms, is arid to locally semi-arid with precipitation ranging from approximately 5 or 6 cm in the basins to about 25 cm at higher elevations. Vegetation on Quaternary fan systems is confined mainly to riparian cottonwood and phreatophytes along active washes and to dispersed Ocotillo and Creosote bush (Larrea Sp.) on modern alluvial fans. Older geomorphic surfaces, characterized by well-developed desert pavement, typically are barren of vegetation except for sparse Creosote. Soils in this portion of the southeastern Mojave are unmapped except for irrigated agricultural land and adjacent terraces (Torrifluvents and Torriorthents) in the Palo Verde Valley along the lower Colorado River (Elam, 1974) and reconnaissance of piedmont fan surfaces around proposed nuclear facilities near Parker and Yuma, Arizona (Bull, 1974a; 1974b).

Field Procedures

Because of the large area covered by the soil-geomorphic survey, many data were obtained by interpreting high altitude (scale 1:125,000), U.S. Air Force aerial photographs, and color small-scale Skylab and ERTS imagery (Shlemon and Purcell, 1976). Where available, recent large-scale photography was also used; as well as field checks by four-wheel drive vehicle, by helicopter and by light aircraft. Additionally, soils within about a 10 km radius of the Sundesert Nuclear site (Figure 1) were described from 24 trenches specifically excavated for that purpose, and from natural exposures in lower, intermediate, and high-level geomorphic surfaces primarily bordering the Mule and Palo Verde Mountains. These surfaces, directly traceable to several dated fluvial terraces of the Colorado River, permit dating and correlating of Quaternary soils and landforms over a wide area in the southeastern Mojave Desert.

Desert Alluvial Systems

The alluvial landforms in the study area are primarily piedmont and pediment fans ranging in age from undissected Holocene deposits to remnant late-Tertiary fanglomerates. As applicable to the southeastern Mojave Desert, these have been described by Denny (1965, 1967), Hadley (1967), Hamilton (1964), Lustig (1966), Melton (1965), Metzger et al. (1973), Olmsted et al. (1973), and Royse and Barsch (1971). These alluvial landforms in the southeastern Mojave Desert appear to have been remarkably stable throughout the Quaternary (Bull, 1964; Shlemon and Purcell, 1976), though tectonism in the western Mojave is well known (Denny, 1967; Hooke, 1967, 1972). It appears geomorphic equilibrium and surface form have been controlled mostly by regional climatic change which affected vegetation, discharge, sediment yield, and a host of minor geomorphic variables. In essence, Quaternary climatic change in this area gave rise to epochs of alluviation preceded and followed by relative landscape stability and soil formation.

Regionally, landform evolution, sedimentation, and pedogenesis in the southeastern Mojave Desert is generally associated with major epochs of Pleistocene pluviality. Whether or not this climatic change can be equated to mid-continental glaciations or interglaciations is still debatable. However, an approximate chronology correlative to Wisconsin and at least two or more Illinoian or earlier stages is borne out by radiometrically-dated multiple lake levels throughout the Great Basin and Mojave Desert (Morrison, 1964, 1965) and in some cases by abrupt sedimentological changes in cores from closed lake basins, interpreted as indicative of climatic change (Smith, 1968). In any event, carbonate depth and morphology in Aridisols greater than about 100,000 years old attest to past climates with effective soil moisture greater than the present.

Classes of Quaternary Alluvium

Four distinct classes of alluvial forms and underlying sediments flank almost all fifteen major mountain ranges in the southeastern Mojave study area (Table 1). These are designated, from younger to older, "Q1" through "Q4." These alluvial forms are differentiated primarily by their surface form and secondarily by their relative soil profile development.

With respect to surface form, two distinct aspects of piedmont fan and piedmont terrace morphology permit their discrimination: (1) relative dissection of fan surface or conversely, preservation of divides, and (2) the amount of desert pavement and its appearance on imagery indicated by reflectance (albedo) of desert varnish (patina).

Relative Dissection of Alluvial Surfaces

Each major periodic change in geomorphic equilibrium, whether induced by local tectonism or controlled by regional climatic fluctuation, resulted in channels being incised into bedrock and existing deposits, and new sediments being carried basinward away from the mountain fronts. Consequently, the other landforms were progressively abandoned as surfaces of transport and eventually dissected. In some cases, the oldest, and now topographically highest surfaces, have little if any original divides remaining. In contrast, the younger, topographically lower surfaces are characterized by progressively better preserved and wider divides.

Table 1. Designation of Alluvial Classes and Approximate Ages, Southeastern Mojave Desert, California and Arizona.

This Study		Lee and Bell, 1975		Bull, 1974a		Hamilton, 1964	
Estimated Ages (yrs)	Alluvial Unit	Estimated Ages (yrs)	Alluvial Unit	Estimated Ages (yrs)	Alluvial Unit	Estimated Ages (yrs)	Alluvial Unit
<15,000	Q_1	0	Q_{a1}	0	Q_4	(None Given)	Q_{a4}
~15,000-200,000	Q_2	0-10,000	Qf	2,000-11,000	Q_3		Q_{a3}
~100,000-500,000	Q_3	30,000-100,000	Qfc	11,000-200,000	Q_2		Q_{a2}
>500,000	Q_4	500,000	QTfc Tf,QTfa	500,000-1,500,000	Q_1		Q_{a1}

Reflectance of Desert Pavement

The vast majority of alluvial fans older than about Holocene-age, are capped by desert pavement, a veneer of gravels derived from adjacent mountain ranges. Where the gravels are high in iron and manganese, emanating from volcanic and metamorphic terrane, a distinctive varnished coating or patina renders these surfaces readily discernible both in the field and on aerial photographs. The relative amount and micro-relief of pavemented surfaces is an excellent geomorphic indicator of landform and soil age.

The origin of desert pavement is not completely understood, with hypotheses ranging from deflation of fine-grained interspersed particles by wind and water (Clements, 1952; Lowdermilk and Sundling, 1950; Lustig, 1966) to mechanical processes causing movement of pebbles to the surface (Cooke, 1970; Denny, 1965, 1967; Springer, 1958). Both hypotheses are applicable in the southeastern Mojave Desert as borne out by inspection of natural cuts in arroyos and trenches specifically excavated for soil description.

The time required for desert pavement formation varies greatly from place to place. In the southeastern Mojave, trails and tracks cut in the pavement during military maneuvers of early World War II show no evidence of "healing." Yet Cooke (1970) has observed incipient renewal of artifically removed pavement in as little as four years. In any event, desert pavement forms only on surfaces that are relatively stable as well as endowed with gravels.

Normally the desert pavement is underlain by 2 to 8 cm of stone-free vesicular silt, especially on the higher and older geomorphic surfaces. The stone-free silty unit, commonly designated A_2 or A_3 eluvial horizons, owes its origin mostly to mechanical disturbance, partially because of wetting or drying, or because of freezing and thawing. As observed by Springer (1958) in western Nevada, repeated wetting and drying of montmorillonite and other expandable-lattice clays is an effective method to move gravels upward in the solum; this process being a function of time as well as of climate.

Another useful indicator to date relatively and to correlate geomorphic surfaces in the southeastern Mojave Desert is the dark-colored varnish or patina characteristic of many desert pavements. The iron and manganese film comprising most desert varnish in part is derived from the rock itself and in part from solution emanating from adjacent weathered soil and debris (Engle and Sharp, 1958; Hooke et al., 1969; Potter and Rossman, 1977). The desert varnish is confined almost exclusively to iron and manganese-rich rocks, and is almost devoid on surfaces characterized by quartzite cobbles or limestone fragments.

The time required for desert varnish formation is still not precisely known. Incipient varnish seems to form in only a few thousand years (Engle and Sharp, 1958; Hooke et al., 1969), but well-patinated surfaces may take tens of thousands of years to develop (Blackwelder, 1948). Varnished pavement greater than about 15,000 years old has likely been subjected to pluviality during the latest Pleistocene, and this paleoclimatic factor may have accelerated the varnishing process.

In brief, the formation and preservation of desert pavement and varnish are excellent indicators for identifying, correlating, and dating relatively intermediate- and high-level geomorphic surfaces throughout the southeastern Mojave Desert. Active fan surfaces, washes and floodplains with little or no pavemented surfaces are probably less than about 15,000 years old (alluvial class Q1; Table 1). Based on limited radiometric and paleomagnetic dates, described in the following section, those well-patinated surfaces with smooth pavement are greater than at least 15,000 years old and more likely 35,000 to about 200,000 years (alluvial class Q2). Locally, some pavement has been partially disrupted by rare surface flow which gives rise to bar and channel topography. Nevertheless, rocks, though transported slightly from their original soils, attest that these surfaces have remained essentially stable since cessation of a previous epoch of alluviation. Those surfaces with obvious deep bar and channel topography, and with none or at best an incipient pavement and varnish, are likely "post-Wisconsin" in age. Higher, and older geomorphic surfaces with well-developed, smooth desert pavement are forming on "pre-Wisconsin" alluvium (Class Q3), and range in age from about 100,000 to 500,000 years old. In some cases, highest remnant drainage divides reflect the aggregate of weathering for the past 500,000 to perhaps 1,000,000 years (alluvial class Q4).

ALLUVIAL SOILS OF THE SOUTHEASTERN MOJAVE DESERT

Description of 22 soil profiles from toposequences of alluvial fans within the southeastern Mojave Desert area indicates that the vast majority of soils are Aridisols, either Orthids or Argids (Shlemon, 1977). Three morphological characteristics of these soils have proven useful for regional correlation and for determining their relative pedological and geological age: (1) the presence and thickness of silty eluvial "A_2" or "A_3" horizons; (2) an argillic horizon usually with 7.5YR or 5YR hues and chromas; and (3) the depth and morphology of calcium carbonate horizons. These three characteristics typify most pre-Holocene alluvial soils in the southeastern Mojave Desert. Thus, the rate of Aridisol development giving rise to these morphological characteristics, may be ascertained more precisely by correlating alluvial fans and geomorphic surfaces to Quaternary sediments dated by radiometric and magnetic techniques.

Torripsamments and Camborthids

As shown diagrammetrically in Figure 2, Torripsamments and Camborthids typify Holocene-age (post-pluvial) surfaces of active fluvial or eolian transport in the southeastern Mojave Desert. Typically, the surface is still sufficiently unstable so that neither desert pavement nor a stone-free vesicular silt have yet formed. Both surface and subsurface horizons are normally 7.5YR and 10YR in color, with cambic horizons limited to soils on distal segments of alluvial fan derived mainly from more easily weatherable metamorphic and volcanic rocks. Not uncommonly, disseminated lime occurs at a depth of about 60 cm (stage 1 development of Gile et al., 1966), the surface epipedon either non-calcareous or slightly calcareous owing to the continual influx of dust. The alluvial fans and basin deposits giving rise to Torripsamments and Camborthids are traceable directly into Colorado River deposits underlying the present floodplain in the Palo Verde Valley dated by radiocarbon as of Holocene age (Metzger et al, 1973; Olmsted et al, 1973).

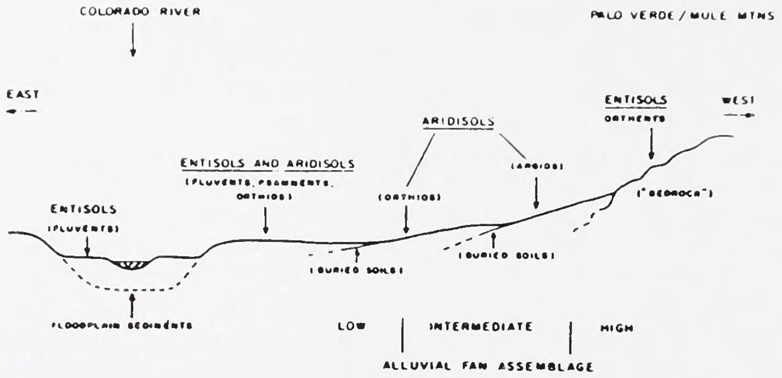

Figure 2 Generalized soil-geomorphic associations showing major soil orders and suborders typical of piedmont fans and pediment terrace, southeastern Mojave Desert, California and Arizona.

Calciorthids

Calciorthids are intimately mixed with some Camborthids on low, intermediate geomorphic surfaces, usually slightly above the present active surfaces of transport. A_2 or A_3 horizons are normally less than 5 cm thick; 7.5YR colors typify the cambic horizon. Carbonate nodules to about 5 mm in diameter occur in sandy matrices, and limey rinds to about 3 mm thick coat the bases of pebbles at a depth of 90 to 120 cm. Where demonstrably pedogenic and not related to buried Cca horizons, this depth of carbonate accumulation suggests, with other geomorphic data, that the soils have been subject to at least one pluvial epoch. Camborthids and Calciorthids, however, are less than about 100,000 years old, based on tracing their underlying parent material to sediments of that age dated by thorium-uranium-protactinium series assay of vertebrate remains (Ku, 1975). In essence, both radiometric dating of soil parent material and geomorphic position indicate a probable "pre-Wisconsin" yet "post-Sangamon" age for Camborthids and Calciorthids in this part of the Mojave Desert.

Haplargids

Haplargids characterize most intermediate-level geomorphic surfaces in the southeastern Mojave Desert. Desert pavement is well-developed with fan remnants sufficiently high above local base level and dissected such that surface flow is derived wholly from contemporary rainfall.

Vesicular horizons underlying the desert pavement typically are about 5 to 10 cm thick, this increasing with elevation and age of fan surface. Argillic horizons are recognizable in the field by a slight increase in clay, reddish-colors (5YR) and presence of illuvial coatings. Whether the clay is wholly translocated or formed in place is unknown, a problem characteristic of argillic horizons in desert soils throughout the southwestern United States (Nettleton et al., 1975). These horizons (Bca) are, however, within the present depth of wetting, for they are typified by stage I carbonates (Gile et al., 1966).

The morphology and depth of the Haplargid Cca horizon is also indicative of age. Nodular carbonates are abundant occupying perhaps 25 percent of surface area, especially on fan sediments derived from metamorphic and volcanic rocks; or downwind from playa lakes, sources of carbonate dust. Lime coatings on pebble bases are 10 to 15 mm thick (stage II) with a dendritic staining pattern on pebble surfaces as well. Calcic horizons are often 140 to 160 cm deep, far below the present depth of wetting in this truly arid terrane (Arkley, 1963).

Paleargids

Paleargids occur on the highest-intermediate level and highest fan remnants and drainage divides in the southeastern Mojave Desert. Desert pavement and varnish are very strongly developed, for except for eolian dust, these geomorphic surfaces have probably not received new sediments during perhaps the last 200,000 years. Landscape dissection is such that the only water available for transport across these surfaces is from local rainfall and not from present drainages originating in adjacent mountain terrain.

Stone-free vesicular horizons are 10 to 12 cm thick; argillic horizons are distinct with colors in the 5 YR range. Illuvial clay is also present except for parent material almost wholly quartzitic where derived from old, reworked Colorado River deposits.

Carbonate depth and morphology also attest to the antiquity of these soils. Carbonate nodules occupy approximately 50 to 60 percent of pore space at a depth of about 150 cm. Incipient K horizons (stage III development) are common (Gile et al, 1965, 1966). These Paleargids, however, are less than 700,000 years old, for they occur on sediments along the lower Colorado River with positive magnetic polarization ascribed to the Brunhes Normal Epoch (Kukla and Opdyke, 1975), and on fans in the Coxcomb Mountains (Shlemon, 1976) containing the approximately 700,000 year old Bishop Tuff, an ash deposit widespread in eastern California (Merriam and Bischoff, 1975).

On highest fan remnants, topographically above surfaces dated as about 700,000 years old, are remnants of well-developed Paleargids. Elevations above local base level are often in the order of tens of metres, such that fan surfaces are strongly dissected and in most cases completely cut off from contemporary deposition except for eolian dust. Desert pavement may be preserved on the wider fan remnants. Elsewhere the surfaces have been stripped so that only a K horizon is preserved, with petrocalcic rubble mantling the adjacent slopes. These high remnants and associated Paleargids, characterized by argillic, Cca and K horizons immediately east of the Chocolate Mountains of California (Figure 1) and on drainage divides within the Trigo Mountains of Arizona (Shlemon and Purcell, 1976). Some of these ancient pedons have plugged carbonate horizons more than two metres thick. The absolute age of these Paleargids and their underlying parent material (alluvial class Q4) is unknown. However, based on their geomorphic position, it appears they may be in the order of at least one million years old.

RATE OF ARIDISOL FORMATION

The radiometrically and magnetically-dated sediments provide an approximate "calibration" for the age and hence rate of Aridisol formation in the southeastern Mojave Desert. Gile and Hawley (1969) and Gile (1975, 1977) report stage I and II carbonate development occurring in Aridisols within Holocene time in southern New Mexico. In the Mojave, in contrast, soils of this age ("post-pluvial") are Torripsamments, Torrifluvents or, at best, Camborthids with only fine disseminated lime.

Haplargids in the southeastern Mojave Desert also appear to be geologically much older than their equivalent profiles in New Mexico based on limited radiometric dating of parent materials in both areas (Gile and Hawley, 1968; Gile et al., 1970; and Gile, 1975, 1977). Whereas Haplargids have formed in the last 10,000 years in southern New Mexico, these soils probably range in age between 15,000 and 100,000 years old in the southeastern Mojave Desert.

Incipient Paleargids in the Mojave Desert require at least 700,000 years to form, at least two to three times longer than that reported by Gile et al. (1970) for southern New Mexico or by Nettleton et al. (1975) for other selected localities in the southwestern United States. Extremely well-developed Paleargids with thick K horizons (laminar) on the highest drainage divides within the southeastern Mojave probably require at least 1,000,000 years to form (Bull, 1974a; Shlemon and Purcell, 1976). Thus the rate of Aridisol formation in this area is probably at least an order of magnitude slower than for comparable profile development in southern New Mexico.

SUMMARY AND CONCLUSIONS

Reconnaissance soil-geomorphic mapping and other studies related to nuclear power plant siting provide new information about the age of alluvial landforms and soils in the southeastern Mojave Desert, California and Arizona.

Four distinct classes of alluvium, designated from younger to older as "Q1" through "Q4," flank some fifteen mountain ranges in a 10,000 sq km area centered around the proposed Sundesert Nuclear Generating Station near Blythe, California. These piedmont and pediment fans range in age from undissected Holocene deposits to remnant late-Tertiary fanglomerates. Regionally, alluviation appears to be climatically controlled, episodically preceded and followed by relative landscape stability and soil formation.

Geomorphic surfaces are differentiated by (1) elevation and increasing surface dissection (preservation of divides); and (2) relative development of desert pavement and varnish (patina). Soil characteristics most applicable for regional correlation and age determination are the (1) presence and thickness of an eluvial (A_2), stone-free vesicular zone below desert pavement; (2) presence of cambic and locally argillic horizons; and (3) depth and morphology of carbonate accumulations.

Torripsamments and Camborthids occur on active surfaces deemed "post-pluvial" or less than about 15,000 years old. Calciorthids and some Camborthids occurring on low, intermediate-level geomorphic surfaces are typified by eluvial horizons generally less than 5 cm thick, cambic horizons and stage I carbonate development. Depth of carbonate below the present average wetting front and geomorphic position suggest a "pre-Wisconsin" soil age. These profiles are, however, less than about 100,000 years old based on correlation with radiometrically dated sediments along the lower Colorado River.

Haplargids in southeastern Mojave Desert occur on intermediate-level geomorphic surfaces. Desert pavement and an underlying silty vesicular (eluvial) horizon characterize these landforms and soils. Cca horizons have stage II carbonate development. From geomorphic position and relative profile development, these soils are greater than about 100,000, and possible as old as 500,000 years.

Paleargids occur on high-intermediate and highest levels in the southeastern Mojave Desert. Desert pavement is limited to narrow divides. Stone-free eluvial, argillic, and strongly developed (stages III and IV) carbonate horizons are characteristic. Incipient Paleargids are somewhat less than about 700,000 years old based on correlating parent material to sediments containing the 700,000-year-old Bishop Tuff, and to those with positive paleomagnetic polarity (Brunhes Normal Epoch).

Strongly developed Paleargids on highest remnant surfaces have Cca and K horizons to two metres thick. This profile development and geomorphic position well above 700,000-year-old dated sediments suggests that these Paleargids may be in the order of at least one million years old.

The rate of Ardisol formation in the southeastern Mojave Desert is substantially slower than that reported for similar flights of geomorphic surfaces in southern New Mexico. Whereas Haplargids have formed within Holocene time in New Mexico, these same soils are greater than 15,000 and possibly up to 100,000 years old in the southeastern Mojave.

Paleargids, similarly, apparently require longer to form. Surfaces stable for about 700,000 years have produced only incipient Paleargids; similar profiles in New Mexico may be as young as Holocene age.

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APPENDIX B

CORRELATION AND AGE OF QUATERNARY ALLUVIAL FAN SEQUENCES, BASIN AND RANGE PROVINCE, SOUTHWESTERN UNITED STATES

(GARY E. CHRISTENSON AND CHARLES PURCELL, 1985)

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Correlation and age of Quaternary alluvial-fan sequences, Basin and Range province, southwestern United States

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ABSTRACT

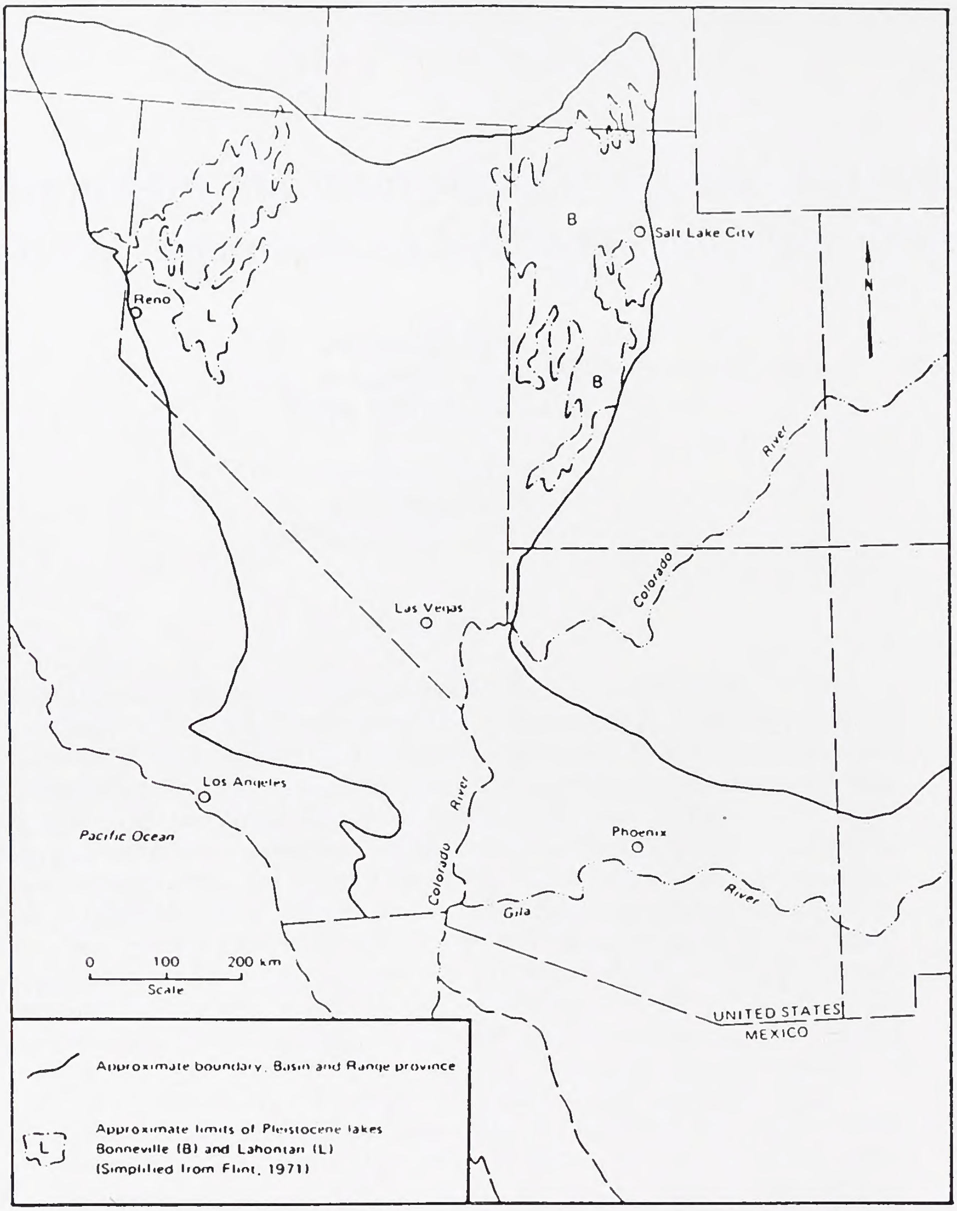
Alluvial-fan deposits in the Basin and Range province in Arizona, California, Nevada, and Utah may be correlated by relative-age criteria. Diagnostic criteria include (1) drainage pattern, (2) incision depth, (3) surface morphology, (4) desert pavement and varnish development, (5) soil-profile development, and (6) morphostratigraphic relations. These criteria allow us to group alluvial-fan deposits into three age classes: young, intermediate, and old. Young fans have a distributary drainage pattern (bar and channel topography), stream incision typically less than 1 m, and an undeveloped to weak soil profile. In contrast, intermediate-age fans have a dendritic to parallel drainage pattern, major channel incision of about 1 to 10 m with undissected interfluves, and weak to strong soil profiles. Old fans retain little of their original surface morphology, have stream incision greater than about 10 m, and typically are cut off from their original source areas by modern drainages. Soils are strongly developed on remnant drainage divides but elsewhere are generally removed by erosion.

Similar sequences of alluvial fans throughout the Basin and Range suggest a regional control over deposition probably related to Quaternary climatic changes. Local variations in sequences may result from other factors which influence deposition, such as lithology and tectonic or other base-level controls. However, fans attributable to these factors are generally not of significance in regional correlation. Relative soil-profile development, morphostratigraphic relations, and absolute dates from numerous Basin and Range localities indicate that most young fans are less than 15,000 years old; intermediate-age fans range from 10,000 to 700,000 years old; and old fans generally exceed 500,000 years in age.

INTRODUCTION

Broad piedmont fan systems cover large areas of the Basin and Range province of the southwestern United States. Each piedmont consists of a complex of coalescing alluvial fans that vary in size, composition, and age. These alluvial-fan deposits constitute a significant part of the Quaternary record in the Basin and Range province, and determining their age is important to reconstructing the Quaternary stratigraphic and tectonic history of the region.

Alluvial-fan deposits vary greatly in age, both within a single fan and between adjacent fans on an alluvial piedmont (summarized in Cooke and Warren, 1973). Several workers have developed similar qualitative techniques to differentiate alluvial-fan deposits according to relative age (see, for example, Denny, 1965; Bull, 1964, 1974b; Shlemon and Purcell, 1976; Shlemon, 1978; and Hoover and others, 1981). Diagnostic criteria used to differentiate alluvial-fan sequences are: drainage pattern, fan morphology, desert pavement and varnish development, soil-profile (pedogenic) development, and morphostratigraphic relations.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Gila
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Scale
UNITED STATES
MEXICO
Approximate boundary, Basin and Range province
L
Approximate limits of Pleistocene lakes Bonneville (B) and Lahontan (L) (Simplified from Flint, 1971)

Figure 1. Location map showing the Basin and Range province and approximate limits of Pleistocene Lakes Bonneville and Lahontan (Flint, 1971).

Many workers in the southwestern United States (Bull, 1974a; Shlemon and Purcell, 1976; Shlemon, 1978; Hoover and others, 1981) have considered alluviation to be climatically controlled. The influence of climate, however, is difficult to recognize in correlating Basin and Range alluvial-fan sequences owing to: (1) differences in interpretation regarding the response of alluvial-fan systems to particular climatic changes, (2) the relatively great sensitivity of alluvial-fan systems to environmental changes other than climate (Ritter, 1974; Bull, 1977), and (3) the small number of well-dated alluvial-fan sequences that can provide accurate time controls for regional correlations or for correlation with known chronologies of climatic change from the deep-sea record (Shackelton and Opdyke, 1976). However, similarities in alluvial-fan sequences studied at several locations throughout the Basin and Range suggest that, in general terms, regional correlations and age assignments are possible. These similarities also suggest that the underlying factor controlling deposition was probably contemporaneous climatic change occurring over large regions.

Accordingly, in this paper we briefly discuss the criteria that are used to characterize alluvial-fan sequences and the potential problems with the use of individual criteria. We then present a three-fold classification for identifying, dating, and correlating alluvial-fan sequences in the Basin and Range. We emphasize the

TABLE 1. GENERAL CHARACTERTISTICS OF YOUNG, INTERMEDIATE, AND OLD ALLUVIAL-FAN DEPOSITS

Characteristic	Young	Intermediate	Old
Drainage pattern	Distributary: anastomosing or braided	Tributary: dendritic	Tributary: dendritic or parallel
Depth of incision	Less than 1 m	Variable (1 to 10 m)	Greater than 10 m
Fan surface morphology	Bar-and-channel	Variable, generally smooth and flat	Ridge and valley, most of surface slopes
Preservation of fan surface	Presently active	Incised, but well preserved wide, flat divides	Basically destroyed, locally preserved on narrow divides
Desert pavement	None to weakly developed	None to strongly developed	None (surface destroyed) to strongly developed (surface preserved)
Desert varnish	None to weakly developed (most varnished clasts reworked from older surfaces or bedrock)	None to strongly developed	None (surface destroyed) to strongly developed (surface preserved)
B horizon	None to weakly developed	Weakly to strongly developed	None (surface destroyed) to strongly developed (surface preserved)
Calcic horizon	None to weakly developed, $CaCO_3$ disseminated throughout	Weakly to strongly developed	None, carbonate rubble on surface (surface destroyed) to strongly developed petrocalcic horizon (surface preserved)

Great Basin, Mojave Desert, and Sonoran Desert (Fig. 1), and we have not included the extensive work done in the Basin and Range of southern New Mexico.

ALLUVIAL-FAN UNITS AND RELATIVE-AGE CRITERIA

Alluvial-fan units defined in this study are based principally on relative-age criteria such as drainage and morphology; desert pavement, desert varnish, and soil-profile development; and morphostratigraphic relations with other Quaternary units. The most consistent and useful of these, particularly when mapping from aerial photographs, are drainage pattern, depth of stream incision, and fan surface morphology. Desert pavement, desert varnish, and soil-profile characteristics, particularly the stage of development of the B horizon and calcic horizon, are also useful, although they are subject to local variations from dependence on many factors other than age (Machette, this volume). Morphostratigraphic relations are important, particularly when ages of related units are known, and are time-equivalent on a regional scale. Examples of such units are deposits and shorelines of large pluvial lakes, tephra layers, and terraces of major through-flowing streams.

At least three general ages of alluvial-fan deposits are found in the Basin and Range province. These include young alluvial-fan deposits marked by active channels with depositional fan surfaces, intermediate-age deposits with well-preserved but inactive surfaces that are incised by modern channels, and old alluvial-fan deposits that have been highly dissected leaving virtually no trace of the original fan surface. Active channels may be mapped separately from active fan surfaces in most instances but for convenience are included with young deposits because they are an integral part of an active surface. Except for minor differences in grouping and terminology, these same three fan units have been used by Hamilton (1964), Bull (1974b), Shlemon and Purcell (1976), Shlemon (1978), Peterson (1981), and Hoover and others (1981). The basic characteristics of these units are shown in Table 1.

Drainage and Morphology

Conditions of erosion and deposition are important in making initial determinations of relative age. The predominance of either erosion or deposition is readily suggested by drainage pattern and morphology. For example, alluvial-fan deposits that are presently aggrading consist of a relatively closely spaced system of braided channels with an overall distributary drainage pattern. These characteristics typically describe the youngest alluvial-fan unit (Table 1; young alluvial-fan deposits). The depth of incision of drainages will generally be less than 1 m and will allow flooding of this young surface during major runoff events. These surfaces, particularly where gravelly, have flood-generated bar-and-channel topography (Fig. 2). In contrast, older alluvial-fan

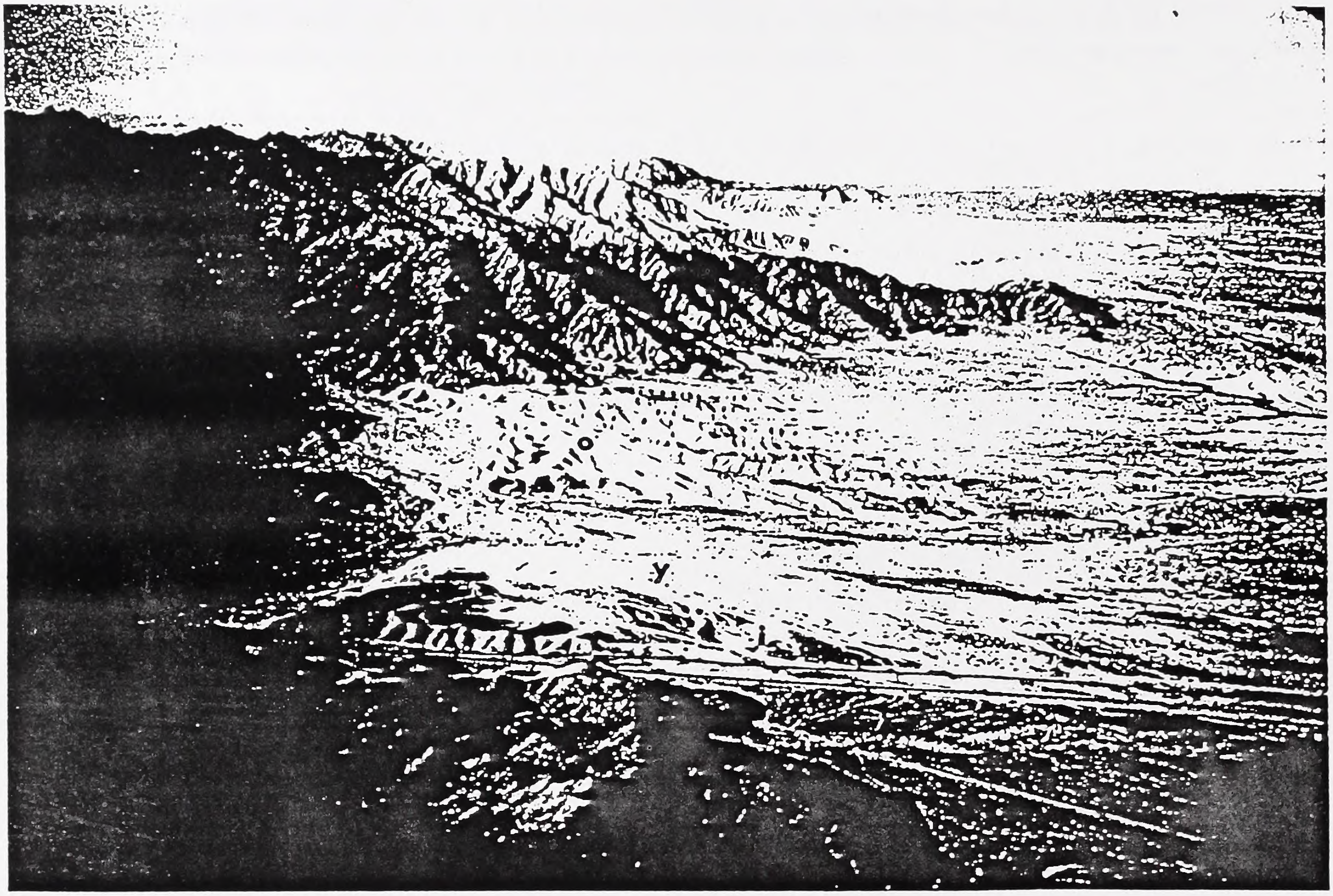

Figure 2. Morphology and desert pavement characteristic of young (y), intermediate-age (i), and old (o) alluvial-fan deposits, northern Gila Mountains, southwestern Arizona.

deposits are undergoing degradation. Drainage on these older deposits is usually an incised dendritic or parallel tributary system. In these deposits, channel incision and fan surface morphology are useful in differentiating relative age. Channel incision depth generally increases with age. Correspondingly, the degree of preservation of original fan surfaces between incised channels generally decreases with age. Intermediate-age alluvial-fan deposits are thus incised but still retain much original fan surface topography (Figs. 2 and 3). In contrast, old alluvial-fan deposits have practically no original fan surface preserved and have interfluves that consist of subparallel ridges (Fig. 2).

Quantitative relations between age and morphologic characteristics are tentative because of the influence of other variables. For example, depth of incision depends on the size of the drainage basin and fan. Large fans with large drainage basins are generally more deeply incised than are smaller fans of roughly equivalent age from smaller drainage basins. Depth of incision and preservation of fan surfaces on interfluves are also influenced by local base-level effects. Alluvial-fan deposits close to an actively degrading base level have a greater depth of incision and poorer preservation of original fan surfaces than do fans of similar age further from these base-level effects, or those in areas of stable or aggrading base levels. Tectonic base-level influences may also create morphologies which are not indicative of relative age (Bull, 1974b). Where fault scarps traverse alluvial deposits, the uplifted blocks between the fault and the mountain front are incised to depths that are more dependent on amount and rate of uplift than on age. Ranges of incision depths shown in Table 1 for each unit are given only as a general guideline, and depths outside the given ranges are not uncommon. Thus, although morphologic characteristics are useful to differentiate relative ages of deposits, other influences are also important for regional correlations.

Desert Pavement, Desert Varnish, and Soil-Profile Development

Several readily observable characteristics of desert soils are useful in evaluating the relative ages of alluvial-fan deposits. Probably the most diagnostic and easily recognized characteristics are desert pavement, desert varnish, and B-horizon and calcic-horizon development. Where soils occur on erosion surfaces cut on alluvial-fan deposits rather than on the original depositional

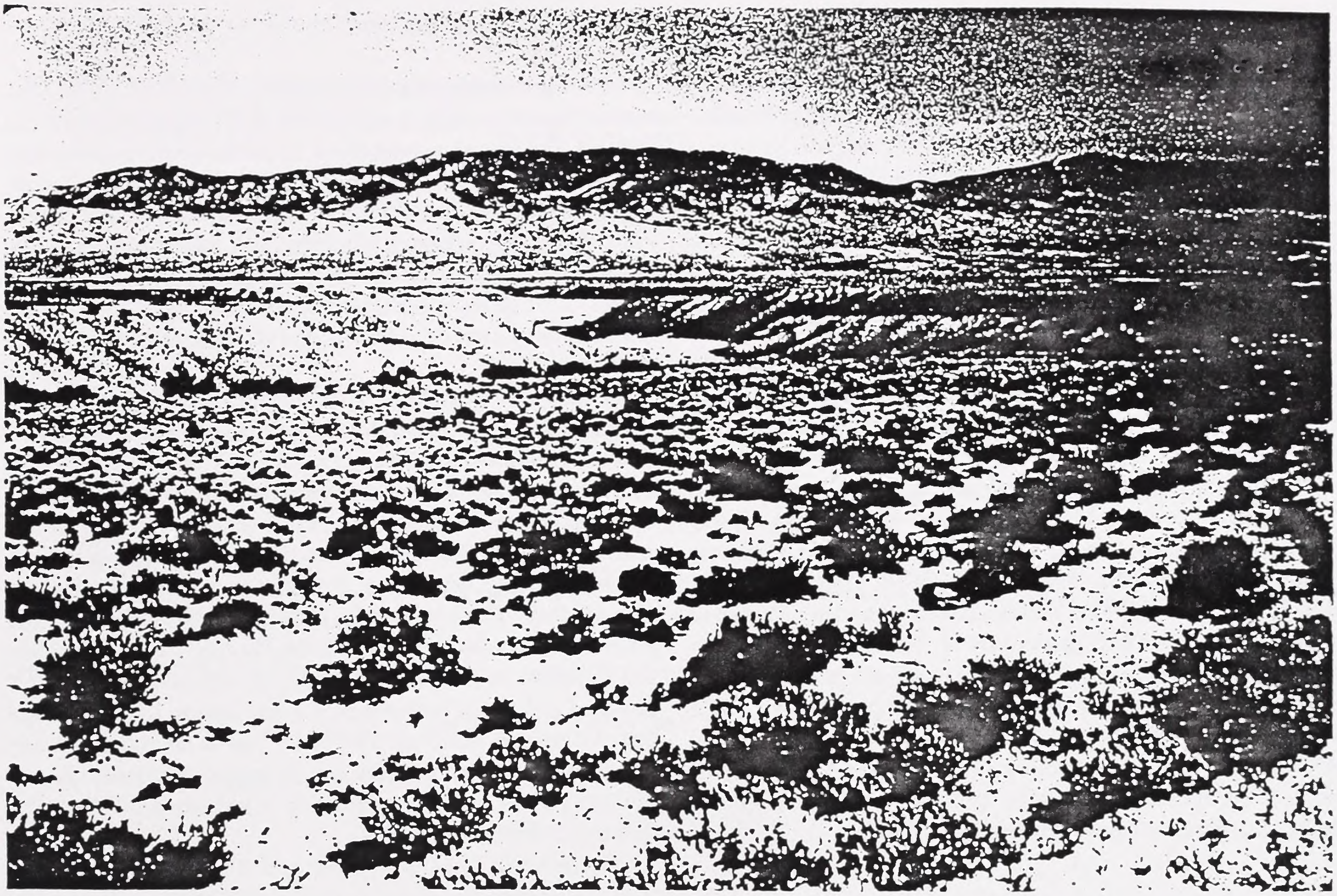

Figure 3. Surface morphology and stream incision on an intermediate-age alluvial-fan deposit, southern Snake Range, eastern Nevada.

surfaces, profile development only provides a minimum age of the deposits; in such cases, fan deposits may be much older than the soils suggest.

In deposits that contain gravel, a desert pavement may develop with time. Young alluvial-fan deposits in general lack pavements because depositional processes are still active. Old alluvial-fan deposits likewise lack pavements because the original fan surfaces have largely been removed by active erosional processes (Fig. 2). The presence of a smooth, well armored surface generally indicates an intermediate-age alluvial-fan surface. These surfaces have a wide range in pavement and varnish development, in part owing to grain-size and regional climatic variations and in part to the wide age range of the deposits. Pavements develop slowly in deposits that contain a small percentage of gravel, but develop very quickly in gravelly deposits and may, in fact, be found on young fans composed of coarse-grained alluvium. In the case of very gravelly deposits, the smoothness of the surface may be a better indication of relative age than is pavement development. The irregular bar-and-channel topography common in gravelly, young alluvial fans becomes progressively less pronounced with age once the surface is abandoned. Intermediate-age fan surfaces, even in very coarse-grained alluvium, are generally quite smooth (Figs. 2 and 3).

With time, desert varnish will develop on exposed clasts in pavements. In addition to age, the amount of varnish is dependent on clast lithology, the availability of eolian dust, and the activity of manganese-concentrating organisms (Hunt, 1954; Engle and Sharp, 1958; Potter and Rossman, 1977, 1979; Perry and Adams, 1978; Dorn, 1983). A very dark varnish may develop on pavements composed of metamorphic and volcanic clasts, whereas varnish may be absent on pavements composed of granitic detritus, chiefly quartz and potassium feldspar. Color of the parent rock is also important because pavements composed of dark-colored clasts may appear more heavily varnished than they actually are. Climate and vegetation must also be considered, because on some fans in the high deserts of the Great Basin enough vegetation is present to preclude formation of pavement and varnish (Fig. 3). Thus, pavement and varnish development may be highly diagnostic of units in a particular area, but because of variations in grain size, clast lithology, climate and vegetation, and availability and composition of eolian dust, it may be difficult to apply these characteristics to regional correlations.

The accumulation of pedogenic calcium carbonate in the B and C horizons and the color and clay content of the B horizon in desert soils are further characteristics for determining relative ages of deposits. Gile and others (1966), Gile and Hawley (1972), Gile (1975, 1977), Bachman and Machette (1977), and Machette (this volume) discuss the progressive development of calcic horizons in the Basin and Range of New Mexico, and Bull (1974b) and Shlemon (1978) present detailed discussions of the development of desert soils in southeastern California and southwestern Arizona. Young alluvial-fan deposits lack soil-profile development because of their youth and aggrading conditions. Old fans may have a strong soil profile where original fan surfaces are preserved, but generally the soil profiles have either been entirely removed or partially truncated. In many instances, calcium carbonate clasts (caliche rubble) scattered on the present surface give evidence of the destruction of a petrocalcic horizon.

Intermediate-age alluvial-fan deposits have varying degrees of B-horizon (cambic to argillic) and calcic-horizon development (Bull, 1974b; Shlemon and Purcell, 1976; Shlemon, 1978; Hoover and others, 1981). Variations in thickness and degree of soil-profile development, particularly in the calcic horizon, stem from differences in lithology, availability of eolian material, climate, grain size, and other factors as well as age (Lattman, 1973; Bachman and Machette, 1977; Machette, this volume). Thus, although soil development can be highly diagnostic in helping differentiate alluvial-fan deposits, local variations in soil-profile development make regional correlations difficult.

Morphostratigraphic Relations

Geomorphic and stratigraphic relations between alluvial-fan deposits and other Quaternary sediments help determine relative age and in some cases help bracket absolute age. Alluvial-fan deposits in the Basin and Range are commonly associated with eolian sand, fluvial terraces, lacustrine deposits and shoreline features, and tephra and other volcanic deposits. The presence of stabilized eolian sand overlying an alluvial fan may indicate that the surface is no longer active. Furthermore, a geomorphic feature representing a local or regional base level to which an alluvial fan is or was graded may indicate relative age. For example, in open drainage basins, successively older fans may be graded to successively higher stream terraces. In closed, aggrading basins, bold surfaces commonly grade below present base level.

In many of these closed basins, morphostratigraphic relations between alluvial fans and pluvial lake shorelines and offshore deposits may indicate relative age. Where stream terraces or lake shorelines extend for great distances, they become useful in regional correlations. This is exemplified by stream terraces bordering the Gila and Colorado Rivers and the shorelines of Lake Bonneville and Lake Lahontan (Fig. 1). Tephra layers, such as the Bishop ash, which are interbedded with alluvial-fan deposits, also provide indications of alluvial-fan age (Shlemon and Purcell, 1976; Hoover and others, 1981).

AGE-DATING OF DEPOSITS

Several workers have successfully correlated alluvial-fan deposits based on relative-age criteria in the eastern Mojave and Sonoran Deserts of southeastern California and southwestern Arizona (Bull, 1974b; Lee and Bell, 1975; Shlemon and Purcell, 1976); western Mojave Desert of California (Ponti and others, 1980; Ponti, this volume); southern New Mexico (Gile, 1975, 1977); southern Nevada (Hoover and others, 1981); and the central Great Basin (Christenson and others, 1982). From these localities, dates have been obtained to calibrate relative-age criteria (Table 2).

Dates shown in Table 2 represent a wide variety of techniques used to date Quaternary deposits. In southeastern California and in southwestern Arizona, Shlemon and Purcell (1976) and Shlemon (1978) have dated deposits based on detailed descriptions of soil profiles and rates of soil-profile development calibrated from radiometrically and paleomagnetically dated sediments and from deposits of Bishop ash contained in the fan material. Bull (1974b) based his chronology on stratigraphic and geomorphic relations of fans with the Pliocene Bouse Formation and Colorado River terrace deposits, as well as on Th^{230}-U^{234} dating of pedogenic carbonates (Ku and others, 1979). Lee and Bell (1975) also relied on Th^{230}-U^{234} dates on pedogenic carbonate in alluvial-fan deposits and on geomorphic relations with Colorado River terraces containing bone fragments dated by amino-acid techniques.

In southern Nevada, Hoover and others (1981) used relations between alluvial-fan deposits, ash beds (including the Bishop ash), and Quaternary and older basalt flows in dating older fan deposits. They have also dated soils and pedogenic carbonates in younger units by the uranium-series and uranium-trend methods. The youngest units are dated by correlation with nearby radiocarbon-dated packrat middens and Holocene alluvial sequences. Similar methods were used by Sowers (1983) to date deposits of the Kyle Canyon alluvial fan in southern Nevada. A new technique utilizing paleomagnetism in pedogenic carbonate was applied in dating older deposits (Sowers, 1982).

In the central Great Basin, radiometrically dated Lake Lahontan and Lake Bonneville shorelines and offshore deposits have allowed dating of associated alluvial deposits. In the Lahontan basin, Hawley and Wilson (1965) indicate that their older alluvium predates Lake Lahontan Sehoo deposits and that the younger alluvium postdates these deposits. Morrison (1964, 1965) and Benson (1978) indicate the time of deposition of the Sehoo deposits to be between about 9,000 and 25,000 years ago. In the Bonneville basin, Christenson and others (1982) identify intermediate-age alluvial-fan deposits that predate the transgression of Lake Bonneville to the Bonneville shoreline, which had probably occurred by about 16,000 years ago (Currey, 1982). The young deposits postdate abandonment of the Bonneville shoreline about 14,000 years ago (Currey, 1982), and in many cases postdate the rapid recession of Lake Bonneville to lower levels as well.

TABLE 2. CORRELATION OF ALLUVIAL-FAN UNITS AND THEIR ESTIMATED AGES IN YEARS BEFORE PRESENT, BASIN AND RANGE PROVINCE

American Southwest		Southeastern California and Southwestern Arizona					
Christenson and Purcell (this study)		Eastern Mojave, California; Shelmon and Purcell (1976)		Eastern Mojave, California; Bull (1974b)		Colorado River, Arizona and California; Lee and Bell (1975)	
Unit	Age	Unit	Age	Unit	Age	Unit	Age
Young	0 to 10,000-15,000	Q1 Q2	0 0-15,000	Q4 Q3	0 <11,000	Qal, Qf	<10,000
Inter-mediate	10,000-15,000 to 500,000-700,000	Q3	15,000 to 500,000-700,000	Q2	11,000-200,000	Qfc	30,000-100,000
Old	>500,000-700,000	Q4	>500,000	Q1	500,000->1,500,000	QTfc, QTfa	>500,000

Great Basin (Nevada and Utah)							
Nevada Test Site; Hoover and others (1981) and Hoover (pers. commun., 1983)		Kyle Canyon, Southern Nevada; Sowers (1983 and pers. commun., 1983)		Lake Bonneville Basin[1]; Christenson and others (1982)		Lake Lahontan Basin[2], Winnemucca area; Hawley and Wilson (1965)	
Unit	Age	Unit	Age	Unit	Age	Unit	Age
Q1	< 8,000-12,000	Surface 4	0-7,000	A5y	<14,000	Younger	<9,000
Q2	110,000->730,000	Surface 3	7,000-35,000	A5i	>16,000	Older	>26,000
		Surface 2	100,000-300,000				
Qta	900,000-1,100,000	Surface 1	>700,000				

[1] Lake Bonneville chronology from Currey (1982)
[2] Lake Lahontan chronology from Morrison (1964, 1965) and Benson (1978)

CONCLUSIONS

From studies throughout the Basin and Range, we group alluvial-fan deposits into young, intermediate, and old units and suggest that these are identifiable and correlative throughout the province. Dates shown in Table 2 indicate that young alluvial fans are generally Holocene or slightly older (less than 10,000 to 15,000 years), intermediate-age alluvial fans cover a broad range from late to middle Pleistocene (10,000 to 700,000 years), whereas old alluvial fans are older than 500,000 years and represent deposition during the early Pleistocene and late Tertiary.

The climatically controlled deposition of young (Holocene) alluvial fans has been discussed by Bull (1974a) and Wells (1977). However, where young alluvial-fan deposits have been dated on the basis of their occurrence below a particular pluvial lake level (Christenson and others, 1982) or on their occurrence stratigraphically above a particular lake deposit (Hawley and Wilson, 1965), they cannot be interpreted as direct evidence of climatically induced change in alluvial-fan deposition. The deposition of these young alluvial-fan deposits is a consequence of lowered lacustrine base levels and is therefore only indirectly related to climatic change.

Regional climatic control over deposition of intermediate-age alluvial fans is less straightforward. These fans include a great variety of deposits which span a period of well-documented climatic change (late and middle Pleistocene time). Although these climatic changes resulted in several distinct levels of intermediate-age alluvial fans recognizable locally, our data are insufficient to attempt regional correlations of different fan levels. Old fans present a similar problem. Nevertheless, the general correlation in age of deposits with similar morphologies and soil development throughout the Basin and Range indicates that, within a certain range of variability, regional correlation and general age assignment (Holocene versus late to middle Pleistocene versus early Pleistocene) are possible. We hope that this tentative chronology will be further refined as more detailed alluvial-fan chronologies are worked out, particularly those dealing with intermediate-age fan deposits.

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APPENDIX C

MESQUITE MINING DISTRICT, SOUTHEASTERN CALIFORNIA, SEG FIELDTRIP

(TOSDAL, ET AL., OCTOBER 1991)

in McKibben, M. ed., Ancient and Modern Mineralization in the Salton Trough, SEG fieldtrip, October, 1991

DAY 1: MESQUITE MINING DISTRICT, SOUTHEASTERN CALIFORNIA

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INTRODUCTION

The Mesquite Mining District lies on the southern piedmont flanks of the Chocolate Mountains in southeasternmost California, some 60 km east of the Salton Sea and about 50 km northwest of Yuma, Arizona (Fig. 1). This range is part of the eastern margin of the Salton Trough, the locus of active faulting along the modern San Andreas fault system (Crowell, 1979) and the locale for this field trip (Fig. 1). Inactive strands of the Neogene San Andreas fault system cut the Chocolate Mountains (Dillon, 1976; Crowell, 1979).

Production from the Mesquite Mining district began in 1985 and is now one of the largest producers of gold in California (Burnett, 1990). Announced economic reserves (Gold Fields Operating Co., 1990) are 93.7 million short tons at an average grade of 0.033 troy ounces per short ton. The Oligocene gold orebodies that constitute the mining district formed in an epithermal environment and are hosted by gneiss and granite of Mesozoic age (see below). This part of the field trip examines the setting of epithermal gold mineralization in the mining district. The structural control on the orebodies is the primary focus of the field trip and we will examine some of the evidence supporting the interpretation of a dextral strike-slip control on the mineralization (Willis and others, 1987, 1989; Manske and Einaudi, 1989). Another structural model links the formation of the gold orebodies to Tertiary extensional deformation and related detachment faulting (Drobeck and others, 1986; Frost and others, 1986). In addition, the effects of post-mineral faulting on the orebodies will be outlined.

Stop 1: Regional Geologic Setting and Overview

The Cargo Muchacho Mountains to the southeast (135°) (Fig. 1B) are composed of plutonic, volcanic, and sedimentary rocks of primarily Jurassic age (Murphy and others,

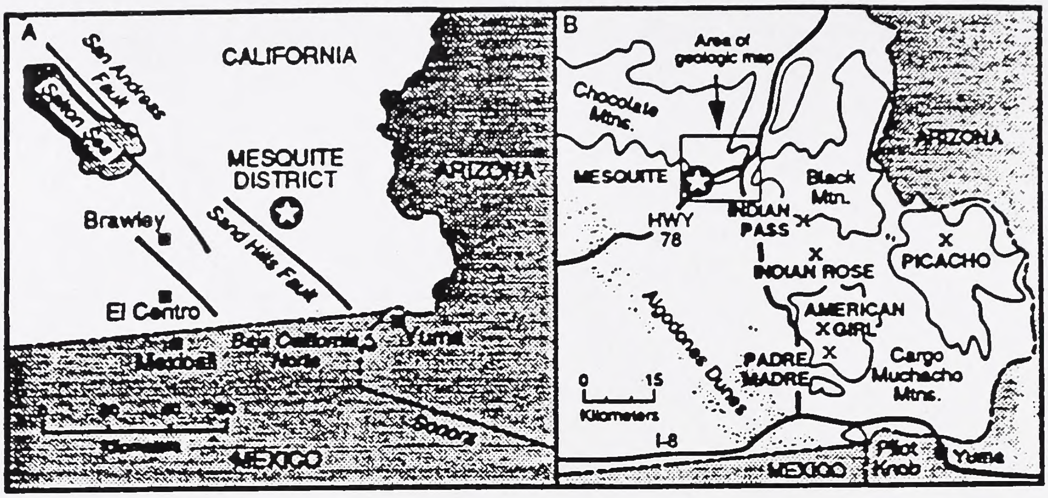


Fig. 1. (A) Location of the Mesquite Mining District in southern California. (B) Location of the Mesquite Mining District, southeastern Chocolate Mountains, and nearby active gold mines and prospects in southeasternmost California.

1990); less common rocks include Proterozoic gneiss, metamorphosed Paleozoic sedimentary rocks, and Late Cretaceous granite. Within the Cargo Muchacho Mountains are located the mines of the American Girl Mining Joint Venture, a 50/50 joint venture between Eastmaque Gold Mines Ltd. and Morrison Knudsen Corporation with the latter as operator. Gold is being mined at a rate of approximately 6000 ounces per month from a combination open pit and underground mining operation (American Girl Mining Joint Venture, 1990). Also within the range are the historic underground workings of the Tumco area, which are also being explored by the American Girl Joint Venture. The orebodies in the Cargo Muchacho Mountains formed during several episodes of mineralization that accompanied (1) prograde metamorphism and plutonism, (2) retrograde metamorphism, and (3) brittle faulting (Morton, 1977; Drobeck and others, 1986; Branham, 1988; Borrastero, 1990).

To the east (110°) (Fig. 1B), near the Colorado River, stands the butte-like Picacho Peak. On the far side of Picacho Peak is the Picacho Mine. Glamis Gold Inc., through its subsidiary, Chemgold Inc., is mining gold from a hematitic rubble zone in the Picacho Mine. Historic underground mining there was concentrated along moderately to steeply dipping veins and breccias (Morton, 1977). Present mining is, in part, along the shallow-dipping contact between the overlying Oligocene volcanic rocks and the underlying Jurassic gneisses (Drobeck and others, 1986; Liebler, 1988). This deposit has been related structurally to a nearby detachment fault, and the low-angle contact between the volcanic rocks and gneisses in the open pits has been interpreted as a detachment fault (Drobeck and others, 1986; Liebler, 1988). However, the low-angle faults in the open pit is post-mineral and crosscuts the volcanic rocks overlying the mineralized zone (G.F. Willis, unpublished data, 1991). Gold production at the Picacho Mine is on the order of 22,000 ounces per year, with current reserves at about 6 million tons grading 0.037 ounces per ton (Chemgold Inc., 1990).

To the east (110°) (Fig. 1B) is Black Mountain which is capped by middle Miocene basalt (Crowe, 1978) (Figs. 1B and 2). The Indian Pass and the Indian Rose/Ocotillo gold prospects are located to the southeast of Black Mountain. The Indian Rose/Ocotillo prospect is being explored under a joint venture agreement between Bema Gold and Glamis Gold Inc. A geological reserve of 5.1 million tons at 0.023 ounces gold per short ton has been announced (Burnett, 1990). Gold mineralization at the prospect occurs in a block of Mesozoic gneiss. The block is rootless, being covered by 60 to 90 m of Tertiary sedimentary rocks and also underlain by Tertiary sedimentary rocks. One possible interpretation of this relationship is that the gneiss has been structurally superposed over the sedimentary rocks during post-mineral faulting. An example of this type of structural geometry will be examined at Stop 5.

To the southwest (225°) (Fig. 1B) beneath the Algodones Dunes is the Sand Hills fault (Fig. 1). This fault is one of the easternmost faults that form the margin of the Salton Trough.

Along the skyline to the north (000°) (Figs. 1B and 2) are the Chocolate Mountains which are underlain by an anticlinorium. The anticlinorium is a composite Late Cretaceous and Tertiary structure consisting of the Orocopia Schist overlain along the south by the Late Cretaceous Chocolate Mountains thrust and its upper plate of Proterozoic, Paleozoic, and Mesozoic crystalline rocks and along the north by low- to moderately-dipping Late Cretaceous(?) and Tertiary exhumation faults and their upper plate of crystalline rocks and Tertiary volcanic rocks (Haxel and Tosdal, 1986; Dillon and others, 1990; Richard and Haxel, 1991). Intruding the Orocopia Schist is the granite of Mount Barrow of latest Oligocene (Frost and others, 1989) or earliest Miocene age (Miller and Morton, 1977). Dillon (1976) argued that the granite is genetically related to the volcanic rocks in the range though this relationship is difficult to document. Abundant miarolitic cavities in the granite indicate a shallow intrusion depth of less than a few km (Dillon, 1976).

The piedmont slopes along the southern flank of the Chocolate Mountains consist of several fault blocks composed of distinct rock units at the surface (Fig. 2). The northernmost fault block consists of dacitic, latitic, and rhyolitic lavas, dome, hypabyssal intrusions, and tuffs (Dillon, 1976), that form the informally named Quechan volcanic

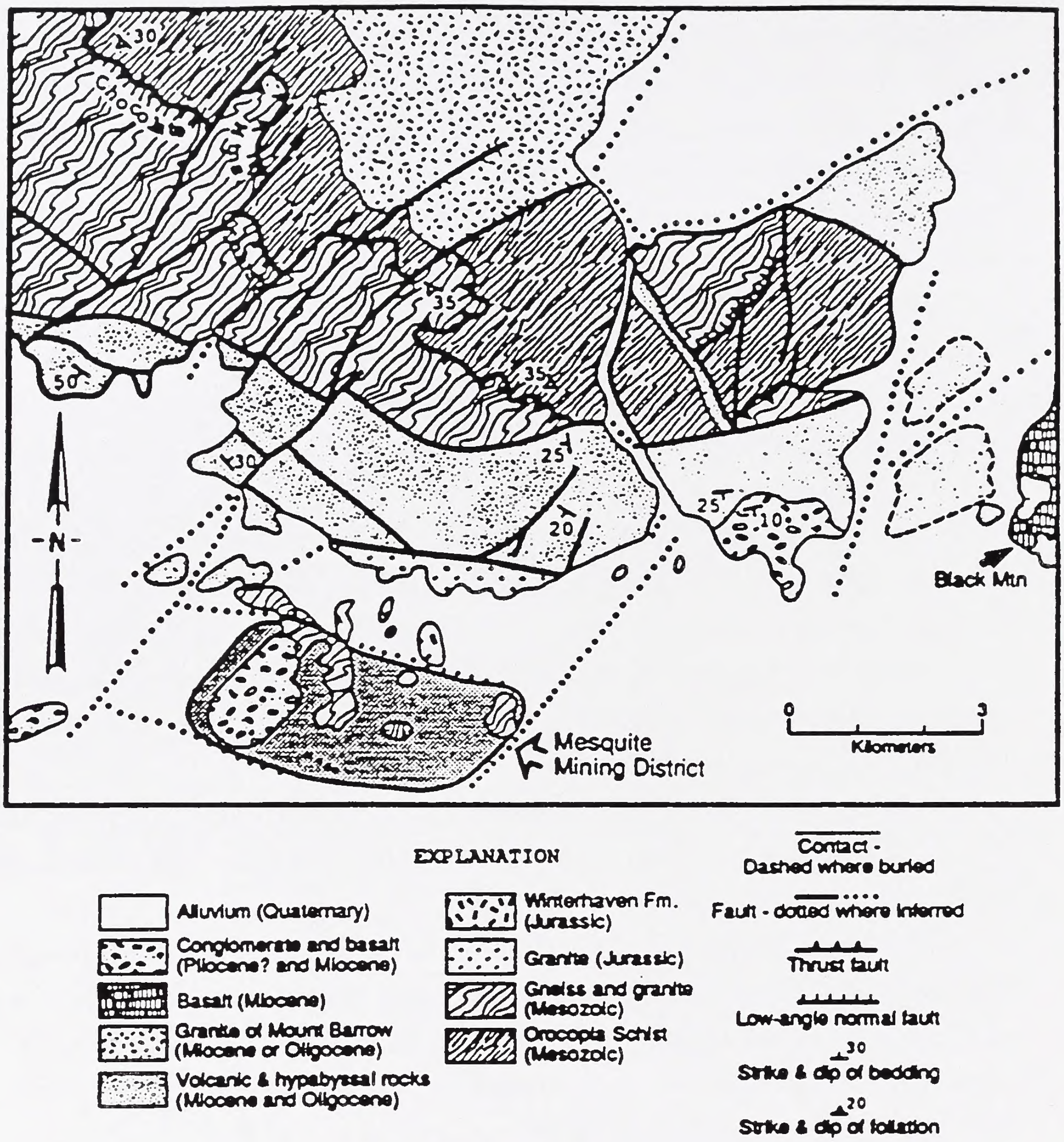
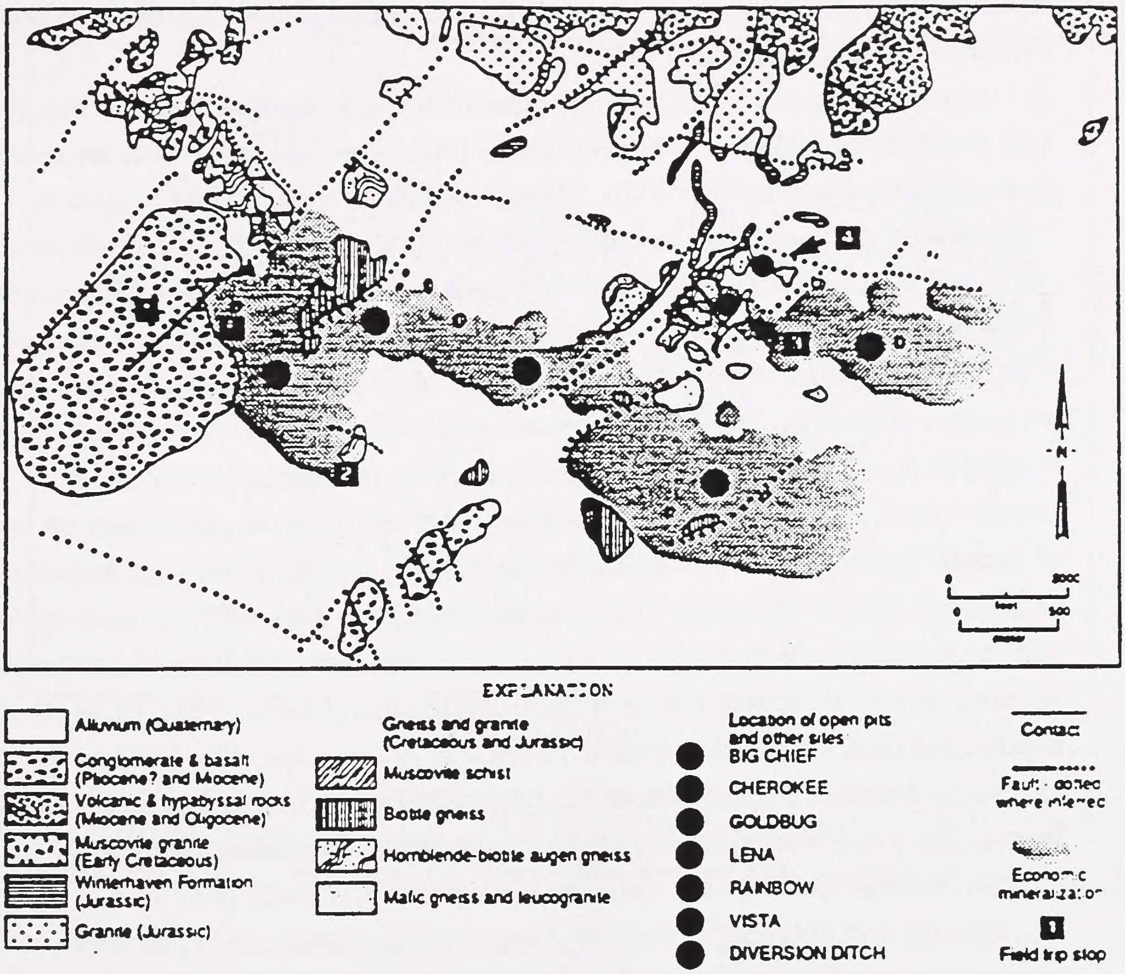

30
CHOCO
35
35
50
30
25
20
25
10
-N-
Black Mtn
Mesquite
Mining District
0
3
Kilometers
EXPLANATION
Alluvium (Quaternary)
Conglomerate and basalt (Pliocene? and Miocene)
Basalt (Miocene)
Granite of Mount Barrow (Miocene or Oligocene)
Volcanic & hypabyssal rocks (Miocene and Oligocene)
Winterhaven Fm. (Jurassic)
Granite (Jurassic)
Gneiss and granite (Mesozoic)
Orocopia Schist (Mesozoic)
Contact - Dashed where buried
Fault - dotted where inferred
Thrust fault
Low-angle normal fault
30
Strike & dip of bedding
20
Strike & dip of foliation

Fig. 2. Areal geologic map of southeastern Chocolate Mountains modified from Dillon (1976) and from Landsat Thematic Mapper image provided by R.G. Blom of the Jet Propulsion Laboratory, California Institute of Technology.

rocks of Crowe (1978). Elewhere in the region, the volcanic rocks unconfomably overlie Mesozoic granitic and gneissic rocks that form the upper plate of the Chocolate Mountains thrust (Dillon, 1976). Available K-Ar geochronology indicates that the volcanic rocks are between about 32 and 26 Ma (summarized by Sherrod and Tosdal, 1991), or essentially the same age as the orebodies in the Mesquite Mining District (see below). It has been argued that these Oligocene igneous rocks, including the granite of Mount Barrow, provided the



N
0 2000 feet
0 500 meter
EXPLANATION
Alluvium (Quaternary)
Conglomerate & basalt (Pliocene? and Miocene)
Volcanic & hypabyssal rocks (Miocene and Oligocene)
Muscovite granite (Early Cretaceous)
Winterhaven Formation (Jurassic)
Granite (Jurassic)
Gneiss and granite (Cretaceous and Jurassic)
Muscovite schist
Biotite gneiss
Hornblende-biotite augen gneiss
Mafic gneiss and leucogranite
Location of open pits and other sites
BIG CHIEF
CHEROKEE
GOLDBUG
LENA
RAINBOW
VISTA
DIVERSION DITCH
Contact
Fault - dotted where inferred
Economic mineralization
Field trip stop

Fig. 3. Generalized geology of the Mesquite Mining District prior to the commencement of mining. Outline of economic mineralization on the piedmont closely correlates with the various orebodies define within the mining district. Mapping by G.F. Willis (1986-1991). Location of faults beneath the alluvium is based on subsurface bedrock mapping based on the results of exploration drilling to the end of 1990.

heat to drive the hydrothermal circulation that resulted in the orebodies in the Mesquite Mining District (Willis, 1988a; Manske 1990, 1991), even though intrusive rocks of this age are yet to be found in the mining district.

To the south across other faults are a block of Jurassic granitic rocks on the north and a block of metasedimentary rocks of the Jurassic(?) Winterhaven Formation on the south (Figs. 2 and 3) (Dillon, 1976; Frost and Watowich, 1987). Exploration drilling through the Winterhaven Formation encountered mafic gneiss at depth similar to that found within the Mesquite Mining district. Elsewhere in the region, the Winterhaven Formation is separated from gneissic rocks by low-angle normal fault(s) of Late Cretaceous and early Tertiary age (Haxel and others, 1985).

Across another fault to the south are quartzofeldspathic gneiss and granite that host the gold orebodies in the Mesquite Mining District (Figs. 2 and 3). These rocks are bounded on the south by a buried fault (Willis, 1988b). Within the mining district, contacts between most gneiss units are moderately and steeply dipping brittle faults characterized by gouge and fault breccia (Willis, 1988a). One unit consists of muscovite schist and gneiss which grades structurally downward into biotite gneiss; these rocks compose much of the Big Chief open pit and contain the highest gold grades. The muscovite schist and gneiss are barren. Hornblende-biotite augen gneiss forms another unit that contains mineralization in all open pits. Mafic and biotite-rich gneiss compose the third major unit and is unmineralized. U-Pb geochronology indicates the protoliths of the gneiss units are largely of Jurassic age though complex crystallization histories preclude precise age determinations (Tosdal and others, 1985; R.M. Tosdal, unpublished data, 1985-1990). Metamorphic mineral assemblages indicate that the gneiss was deformed at amphibolite facies conditions. A coarse-grained muscovite granite of Early Cretaceous age (105±10 Ma) (R.M. Tosdal, unpublished data, 1986-1990) intrudes the gneisses as stocks and sills. Foliation parallel and mildly deformed leucogranite, aplite, and pegmatite sills, also of Cretaceous age (D.M. Frost *in* Frost and Watowich, 1987; R.M. Tosdal, unpublished data, 1986-1990), are common throughout the gneiss. Foliation in the gneiss dips gently (<30°).

Miocene and Pliocene(?) sandstone, conglomerate, siltstone, and sparse interbedded basalt unconformably overlie the gneissic rocks in the mining district (Fig. 3) (Manske and others, 1987; Willis, 1988a, b). These rocks are considered equivalent to the Miocene and Pliocene(?) conglomerate of Bear Canyon (Dillon, 1976; Crowe, 1978), a widespread and poorly understood unit in southeastern California. Unconsolidated Quaternary alluvium on pediments and in the washes cover most of the rocks.

Late Cenozoic faults along the southern flank of the Chocolate Mountains generally dip steeply and in map pattern are curvilinear (Fig. 2) (Dillon, 1976). In the vicinity of the Mesquite Mining District, the traces of the major faults strike westerly across the pediments. The fault traces bend toward northwest strikes to the northwest and to northeast strikes to the northeast of the district. Bedding within the Oligocene tuffaceous rocks also reflects the bends, though the data are not systematic and there are dip reversals and folds (Dillon, 1976). Manske and others (1987) suggest that the fault that bounds the mining district on the north had some dextral slip. However, the magnitude and sense of displacement on most of the major faults is unknown, but could be as much as several kilometers because of lithologic mismatches across the faults. Throughout the Chocolate

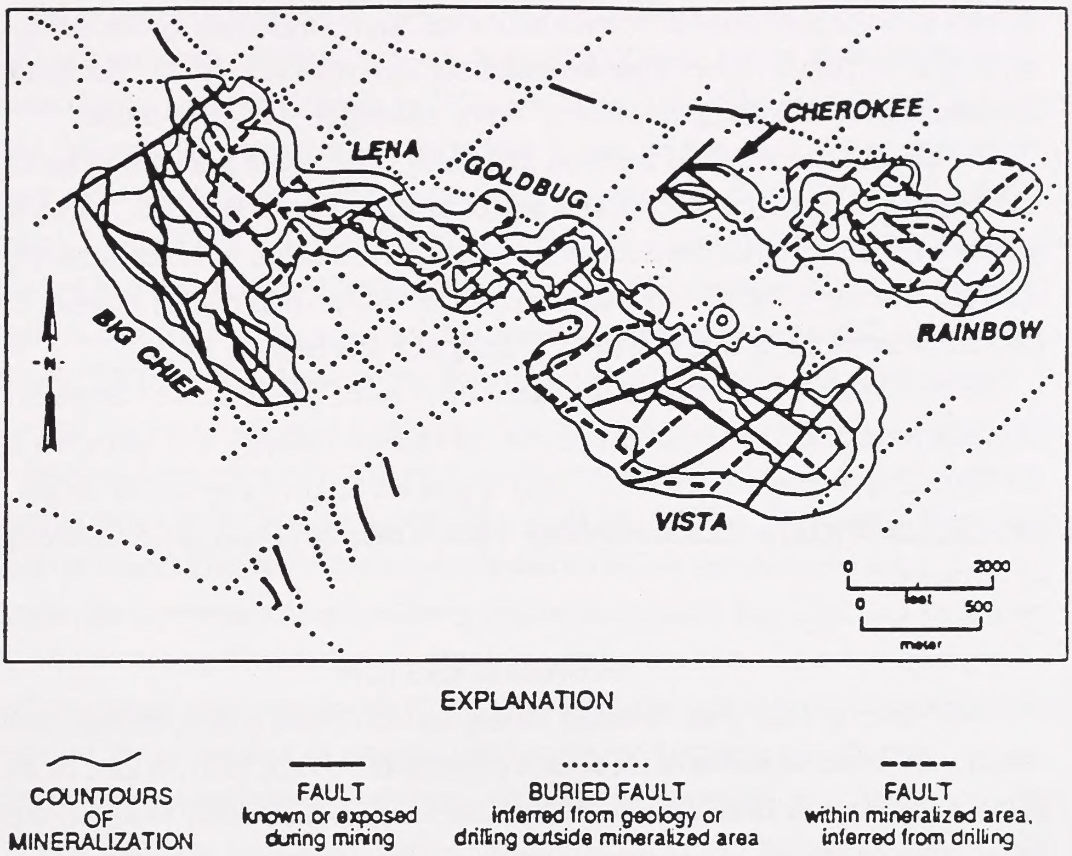

CHEROKEE
LENA
GOLDBUG
BIG CHIEF
N
RAINBOW
VISTA
0
2000
feet
0
500
meter
EXPLANATION
COUNTOURS OF MINERALIZATION
FAULT known or exposed during mining
BURIED FAULT inferred from geology or drilling outside mineralized area
FAULT within mineralized area, inferred from drilling

Fig. 4. District-scale fault map showing orebodies in their present configuration. Known faults within open pits are based upon their exposure as mining has progressed. Location of inferred faults throughout mining district is based on the results of exploration drilling.

Mountains, left-separation and left-lateral strike-slip faults with northeast and easterly strikes offset the northwest-striking faults, lithologic contacts, and the Chocolate Mountains thrust (Dillon, 1976) (Fig. 2). Northeasterly striking faults dissect the orebodies in the Mesquite Mining District where they are largely post-mineralization and cut northwest striking faults that are mineralized (Figs. 3 and 4) (Stop 5).

At least two ages of fault movement can be documented. The oldest was contemporaneous with formation of the orebodies in the Oligocene, as gold mineralization fills these faults. Primarily northwesterly and northerly striking faults moved at this time (Willis, 1988a). The second episode occurred after about 11 Ma as the middle Miocene and Pliocene(?) sedimentary rocks and basalt are cut by these faults. Movement at this time was primarily along northeasterly-striking left-lateral oblique-slip faults; the older northwest-striking mineralized faults were reactivated at this time. It seems likely that this episode of faulting is related to the evolution of the San Andreas fault system and the opening of the Salton Trough since the middle Miocene (Crowell, 1979). The tectonics of the older episode of faulting that occurred during mineralization is problematic.

The conspicuous feature of the Mesquite Mining District seen from here is the Big Chief open pit (Figs. 3 and 4). The long axis of the pit trends roughly 315°, which is the general trend of mineralization throughout the district. Farther to the southeast is the Vista open pit. The Big Chief and Vista open pits will be connected as mining proceeds along the northwesterly Lena/Gold Bug trend. Mining here will begin in 1993.

To the northeast across a block of unmineralized mafic gneiss are the Cherokee-Rainbow orebodies. The Cherokee open pit, the northern orebody, was mined out in 1988. It contained approximately 1.7 million tons of gold ore at 0.033 troy ounces per ton. To the southeast of it is the Rainbow orebody, which is currently in the pre-production phases of stripping.

MINERALIZATION

Gold-bearing veins in the Mesquite Mining District formed in an epithermal setting within a few hundred meters of the surface (Manske and others, 1987; Willis, 1988a, b; Manske and Einaudi, 1989; Manske, 1990). The veins are moderately to steeply dipping and are fault controlled. K-Ar ages for sericite (Willis, 1988a) and $^{40}Ar/^{39}Ar$ ages between 32 and 26 Ma (Frost, 1990) indicate an Oligocene age of mineralization.

Two vein types contain gold in the mining district. Quartz±pyrite±adularia±electrum veins with weakly sericitic selvages are the principal gold-bearing structures in the Big Chief open pit (Willis, 1988a, b; Manske, 1990, 1991). Two stages of quartz-cemented breccias are contemporaneous with the veins and are common in the parts of the pits with the highest gold grades (Willis, 1988a; Manske, 1990). Some quartz veins grade into chalcedonic veins. A second type are gold-bearing ankerite-dolomite-pyrite veins form the orebodies in the Cherokee and Vista open pits where quartz veins are relatively minor. Gold-bearing ankerite-dolomite veins also post-date quartz and some chalcedonic veins in the Big Chief open pit (Willis, 1988b). In contrast to this paragenesis, Manske (1990) argues that ankerite-dolomite veins in the Big Chief open pit are gold-bearing only where they occupy reopened older auriferous quartz veins. Barren calcite veins cut the mineralized veins in the Big Chief, Cherokee, and Vista open pits, and still younger chalcedonic vein cut calcite veins at least in the Big Chief pit (Manske, 1990). Weakly anomalous concentrations of Au, Ag, As, Sb, Hg, W, Zn, and Te were sporadic in surface rock samples prior to mining (Tosdal and Smith, 1987).

Vein deposition occurred by episodic open space filling as evinced by vuggy and comb quartz and carbonate minerals, by multiple banding of veins, and by clasts of veins and breccia in other breccias (Manske and Einaudi, 1989; G.F. Willis, unpublished data, 1986-1991). Veins range from micro-cracks to breccias that are 6 m thick. Weak sericitization of host rocks accompanied gold mineralization (Manske and others, 1987; Willis, 1988a, b; Manske, 1990). Fluid inclusion data from the Big Chief open pit indicate that electrum was deposited in quartz veins and breccias from a boiling, CO_2-bearing solution of roughly 1 weight percent NaCl-equivalent in salinity with a temperature between 210° and 225°C (Manske, 1990, 1991). Based on the fluid inclusion data, Manske and others (1987) estimated that the quartz veins in the Big Chief open pit formed at a depth of 200 to 300 m.

Northwesterly, northerly, and westerly striking mineralized faults and veins are the structural trends throughout the district (Fig. 4) (Willis, 1988b). The relative importance of one set of mineralized structures versus another set differs between ore bodies. For example, the northwesterly and northerly sets are important in Big Chief and Vista open pits, whereas the northwesterly and westerly are important in the Cherokee open pit. As noted previously many, but not all, of the mineralized faults have been reactivated, thereby converting the mineralized structures to clay gouge and microbreccia. No new hydrothermal mineralization accompanied this last movement.

Stop 2: Mineralization in the Big Chief orebody

The southeastern end of the Big Chief orebody contains an example of the important structural controls on gold mineralization in the mining district. The mineralization here lies in upward-diverging mineralized faults and veins (Figs. 3 and 5A) that geometrically resemble a positive flower structure like those common in strike-slip fault systems (Harding, 1985). The flower structure is approximately parallel to the axial surface of an upright fold in the foliation in the gneiss. All vein types are present on the open pit wall.

In detail, the southeast corner of the open pit consists of hornblende-biotite augen gneiss that in general is poorly mineralized, though locally the gneiss is cut by some high-grade veins. The gneiss lies in the footwall of a southwest-dipping fault which contains biotite gneiss in the hanging wall; this fault is the northeast margin of the flower structure. Other faults are present across the pit wall, and the southwest margin of the flower structure is formed by a northeast-dipping fault which contains biotite gneiss in the hanging wall and footwall. Each fault has been reactivated subsequent to mineralization and is now characterized by gouge derived from veins and stockworks. This post-mineral faulting has downdropped Tertiary sedimentary rocks against gneiss.

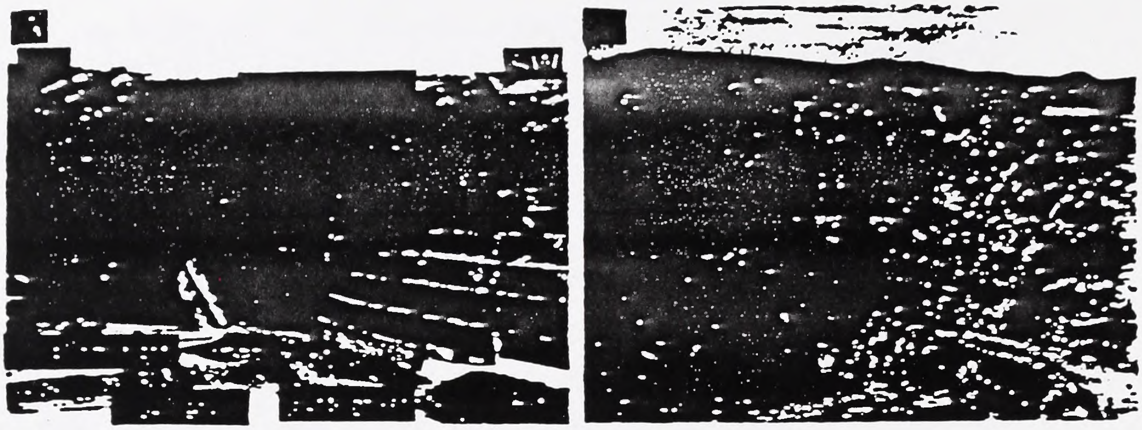


Fig. 5. (A) Positive flower structure in the southeastern end of Big Chief open pit. (B) Flower structure in the west end of the Cherokee open pit. Mineralized faults that compose the flower structures on the bench faces are solid lines and on the bench floors are dashed. Foliation in the host gneiss is shown by dotted lines. Benches are 20 ft (6.1 m) high.

The northeast fault of the flower structure is a major locus of gold mineralization in the Big Chief orebody and forms a part of the high grade core of the ore body. A major zone of high grade (≥0.10 troy ounce Au per short ton) mineralization that ranges from less than a foot to tens of feet in width lies in the hanging wall of the northeast margin of the flower structure. Multiple high-grade quartz and carbonate veins are present in the fault. Gold-bearing veins extend into the hanging wall as a stockwork. Veins are extensive in the hanging wall of all faults in the flower structure, as well as throughout the open pits in the mining district (G.F. Willis, unpublished mapping, 1986-1991; Manske and Einaudi, 1989; Manske, 1991).

Stop 3: Cherokee open pit overview

The west end of the Cherokee open pit offers another cross sectional view of the fault control on gold mineralization in the mining district (Fig. 3). The Cherokee orebody lies in a dilational jog (Sibson, 1987) bounded by faults in the north and south walls (Fig. 5B). Mineralization occurred in upwardly-diverging faults and veins that form a flower structure crosscutting hornblende-biotite augen gneiss. Ore-grade mineralization in the upper benches was laterally distributed from the north wall to the south wall, in a discontinuous zone up to 400 ft (120 m) wide. With depth, the mineralized zone narrowed toward a central core of the pit, with the ore grade gold mineralization being confined to a 30-ft (9.1 m) wide stem that was mined with a bulldozer to extract the last remnants of economic mineralization.

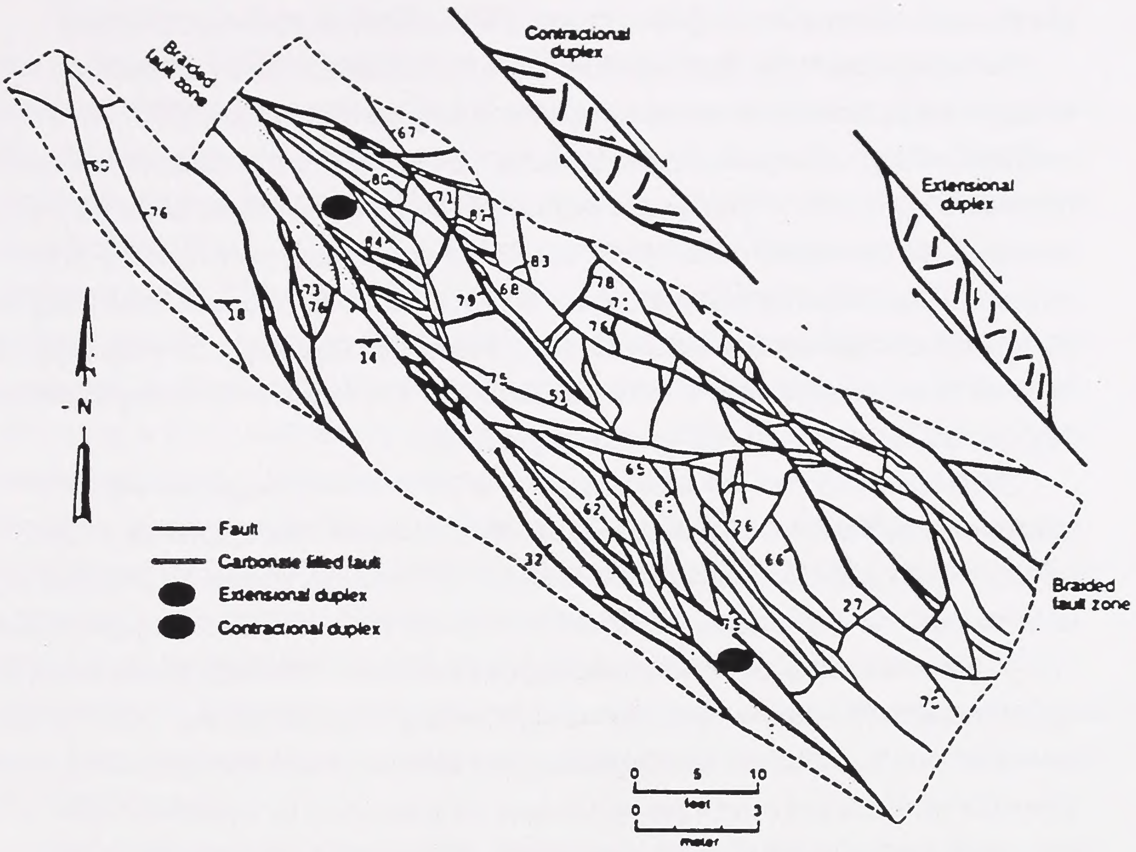


Fig. 6. Structural map of the diversion ditch along the northeast margin of the district block. Also shown are simplified diagrams of the fracture and fault patterns in extensional and contractional duplexes as adapted from Swanson (1990).

Stop 4: Diversion ditch--Small scale model of the Mesquite Mining District

A flood diversion ditch excavated during 1989 along the northern margin of the district, northwest of the Rainbow orebody and east of Cherokee open pit (Fig. 3), exposed an anastomosing fault system and accompanying ferroan carbonate veins and mineralized faults. Here, two braided fault zones, both of which dip steeply, bound a block cut by numerous faults and fractures (Fig. 6). The braided fault zones are northwesterly striking and consist of numerous lozenges of intact rock that are bounded by faults commonly filled with brown carbonate minerals. Internal fracturing and veining of lozenges is pervasive. Deformation is interpreted to have been most intense along the braided zones. Between them, steeply dipping faults consist of northwesterly striking faults of various orientations, northerly striking faults that commonly are short segments connecting northwesterly striking faults, and a few faults that strike northeasterly and in several sites define the ends of competent rocks such as pegmatites. Faults within each set have opposing dips.

The fault pattern in the ditch is divided into a two domains, which geometrically resemble contractional or extensional duplexes in map view (Swanson, 1990). A contractional duplex lies at the northwest end of the ditch whereas an extensional duplex forms the southeast end. Within these duplexes the relative orientations of the northwest trending faults are slightly different with the general trends being more northerly in the extensional duplex than in the contractional duplex. Moreover, carbonate veins along the faults and intra-fault blocks are more abundant within the extensional strike-slip duplexes as would be expected because of increased dilatancy. The map-view geometry of the two duplexes is consistent only with dextral simple shear.

The diversion ditch can be used as a model of the structural complexity and its influence on the distribution of mineralization in the Mesquite Mining District. In this model, the gold orebodies would be located in the area between the two braided fault zones in extensional and contractional duplexes and in dilational and antidilational jogs (Sibson, 1987). Extension duplexes and dilational jogs would be most favorable for the influx of hydrothermal fluids whereas contractional duplexes and antidilational jogs would be less favorable for mineralization. This is precisely the situation seen in the Big Chief open pit where the southeast and narrow part of the open pit is occupied by a positive flower structure (Stop 2), an area of relative contraction, and the widely dispersed mineralization in the northern end of the open pit is comparable to a composite dilational jog, an area of relative extension (Manske, 1991; G.F. Willis and R.M. Tosdal, unpublished data, 1991). It is critical to recognize that both types of duplexes and fault jogs are mineralized in the mining district and, though they are geometrically similar to one another, each structure has a different implication for future exploration, particularly where post-mineral faulting has been important.

POST-MINERAL FAULTING

Post-mineral faulting has reactivated many mineralized faults, particularly in the Big Chief and Vista open pits. Reactivation of mineralized structures is relatively minor in the Cherokee open pit where veins are coated with a thin film of clay or gypsum. The reactivated faults pass upward through the orebodies and in many case downdrop post-mineral sedimentary rocks and basalt against mineralized gneiss. Two fault sets are evident, both of which are primarily steeply dipping. Where moderate to shallowly dipping faults occur, they are controlled locally by the gentle dipping foliation in the gneiss and generally these faults steepen with depth.

The northwesterly to northerly striking post-mineral faults follow older mineralized structures in the Big Chief and Vista open pits. The sense of movement along most northwest-striking, reactivated faults is dependent upon the dip direction of the older faults, though most faults have normal separations. For example, the northeast side of northeast-dipping faults is downdropped, whereas the southwest side of southwest-dipping faults is downdropped (Fig. 5A). Other faults have more complicated displacements. The southwest margin of the Big Chief open pit in its upper benches was defined by a shallowly southwest-dipping thrust complex in which muscovite schist is superposed over gneiss and, in places, over Miocene sedimentary rocks. Thrust fault duplexes formed of alternating layers of sedimentary rocks and muscovite schist are present. The thrust faults steepen with depth. Other northwest-striking and steeply southwest-dipping faults superpose gneiss over the Miocene sedimentary rocks in a thrust sense though in many cases the inclined clayey gouge fabrics (Chester and Logan, 1987) along the faults indicate dextral strike-slip motions. Elsewhere in the Big Chief open pit, inclined clayey gouge fabrics along the faults indicate both normal and dextral strike-slip displacements on different faults. Regardless of the sense of motion, the separation on any post-mineral fault is not large, measured in ten's of meters. A possible exception is the thrust complex in the Big Chief open pit.

The northeast-striking post-mineral faults disrupt the gold orebodies to a greater extent that the northwest-striking reactivated faults. These faults indiscriminately cut mineralized faults and veins as well as westerly striking faults that bound the mining district (Fig. 4). Separation along these faults is normal. However, inclined clayey gouge fabrics in several faults also imply a component of left-lateral strike-slip movement. Throughout the mining district, left bends in the presently defined outline of gold mineralization on the piedmont surface correspond to traces of the northeast-striking faults (Figs. 3 and 4).

The northeasterly striking faults are evidently left-lateral oblique-slip faults, as evinced by the kinks in the economic mineralization, observed fault separations, small-scale kinematics, and the regional relations throughout the Chocolate Mountains (Dillon, 1976; G.F. Willis and R.M. Tosdal, unpublished data, 1990). One consequence of this episode of faulting is that the present configuration of the orebodies in the Mesquite Mining District is an oblique slice through the Oligocene orebodies. In other words, different levels of the hydrothermal system responsible for the orebodies are exposed in adjacent fault blocks with the shallowest levels represented by the auriferous quartz and carbonate veins in the Big Chief orebody and the deepest levels by the auriferous carbonate veins in the Vista orebody. In addition, the mining district may have been locally tilted slightly at this time though the geometric compatibility of the mineralized fault system to a dextral strike-slip fault in its present configuration and the shallow dips of the Miocene and younger sedimentary rocks and basalts limits the amount of tilting of individual fault blocks in the district to ≤ 20°, primarily northwesterly or southeasterly (G.F. Willis and R.M. Tosdal, unpublished data, 1986-1991; Manske, 1991). Left-lateral oblique slip faulting along the northeast-striking faults also provides a structural context for the northwest-striking, post-mineral faults. These latter faults are evidently intra-block faults and their movement must have been linked to left-lateral oblique-slip on the northeasterly faults. The northwesterly-striking post-mineral faults thus are best explained as structures which accommodated block rotation during movement along northeast-striking faults. Because the northeast-striking faults are curviplanar, as evidence by their curvilinear traces on the piedmont (Fig. 4), there must have been some relative extension or shortening across the intervening blocks (Crowell, 1974). In the case of rotating blocks bounded between two faults having oblique-slip displacements and where there is shortening or extension between the oblique-slip faults, complex internal movements are required between the rotating blocks to accommodate the strain (McKenzie and Jackson, 1986; Jackson and Molnar, 1990). The evidence for thrust, strike-slip, and normal slip on the northwest-striking post-mineral faults in the Mesquite Mining District is best explained by this model.

Stop 5: Post-mineral faulting

In the extreme northwestern corner of the Big Chief pit are some of the more complex results of the post-mineral faulting. Here, muscovite schist is in relatively high angle fault contact with the sedimentary rocks on the south side of the 740-ft bench-face. In contrast near the top of the bench-face, the muscovite schist is overlain by sedimentary rocks along a low-angle fault contact. Farther along the north side of the bench-face, the muscovite schist and sedimentary rocks form a thrust fault duplex consisting of structurally-bounded layers of sedimentary rocks and muscovite schist. A thrust fault geometry also characterized the central portion of the Big Chief orebody at a large scale where muscovite schist overlay the orebody along a shallow-dipping fault in the upper benches of the open pit. Biotite quartzofeldspathic gneiss formed the footwall to this thrust fault. As mining progressed, the muscovite schist was removed exposing the mineralized gneiss. The low angle faults steepened and merged with a high angle fault zone that separated muscovite schist and biotite gneiss on the west side of the orebody.

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APPENDIX D

LETTER TO ENVIRONMENTAL SOLUTIONS, INC. : RESPONSE TO QUESTIONS DRAFT REPORT - FAULTING AND SEISMICITY IN THE VICINITY OF THE MESQUITE REGIONAL LANDFILL, 1992.

(HEATH, 1992)

EDWARD G. HEATH
CONSULTING ENGINEERING GEOLOGIST

Dr. Richard Ellison - President
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RE: Response to questions - Draft Report - Faulting and Seismicity in the vicinity of the Mesquite Regional Landfill

Dear Dr. Ellison:

At the request of Mr. Marshall Payne, I was asked to address some of the review questions relating to the subject draft report. Some of these questions reference prior work that I and others have done in the area, see Woodward-McNeill, 1974 and Heath, 1980. Based on this prior experience in the area and on a review of recent work by others, I have prepared this letter report to address the issues raised. Of primary concern are: the possible existence of the Sand Hills faults located approximately 7-9 miles west of the proposed landfill site; the question of these postulated faults connecting with or being an extension of the San Andreas Fault; and the earthquake hazard to the site from these and other faults in the Imperial Valley.

Sand Hills Faults

California State geologic and fault maps published prior to 1974, ie, Geologic Map of California, C.D.M.G., 1962; Geologic Map of Imperial County, C.D.M.G., 1966; and Preliminary Fault and Geologic Map of California, C.D.M.G., 1973, showed postulated faults trending along both sides of the Sand Hills. These faults were shown as covered by recent alluvium consisting of sand and fluvial deposits. There were no mapped surface exposures and the faults' locations were based upon the apparent linearity of the Algodones Sand Hills. Subsequent to the publication for these maps many geologists and geophysicists have studied the area, including the author, in attempts to confirm the existence of these postulated faults and to see if they represent a southern extension of the San Andreas Fault Zone. The more pertinent and more recent studies are discussed briefly in the following paragraphs.

In their early geophysical studies of the western side of the Salton Trough, Kovach, Allen, and Press, 1962, could not confirm the existence of the Sand Hills faults along the edges of the Sand Hills nor could they confirm that they represented a southern extension of the San Andreas Fault Zone. They stated that the San Andreas Fault Zone more likely enters the Gulf of California as a series of en echelon breaks rather than as a single fault feature.

Elders and other, 1972, have elaborated on this concept by relating rifting in the Salton Trough to crustal spreading and to right-stepping transform faults and postulated that the San Andreas Fault ends at a spreading center south of the Salton Sea. They show that farther south, right-stepping en echelon transform faults and spreading centers extend the length of the Gulf of California.

In their review of the tectonic framework of the San Andreas - Salton Trough juncture, Terres and Crowell, 1979, summarize the research conducted and published by many others, (see Crowell & Sylvester, 1979). They conclude that; although the complex transform - pull-apart system in the Southern California - Gulf of California juncture is obscured today beneath sediments in the Salton Trough; the San Andreas, San Jacinto, and Elsinore faults each end at spreading centers or pull-apart basins. They further conclude that the Salton Trough is in a transition zone where crustal rifting processes have interacted with transform faulting to form a series of large pull-apart, interconnected deep basins. In the same publication, Crowell and Sylvester, 1979, show the San Andreas stepping over to the west south of the Salton Sea and show only normal, down-to-the-west faulting along the area of the Sand Hills. Thus the San Andreas proper apparently ends in an active, pull-apart basin at the south end of the Salton Sea.

In a further investigation of the structure of the Imperial Valley and related geothermal activity, Elders, 1984, pointed out that recent geophysical studies of the Imperial Valley have shown that it consists of a trough of sedimentary and metasedimentary rocks as much as 10-16 km deep and that the deepest part of the trough coincides with the zone of highest seismicity in the center of the valley. This central zone of present-day rifting is bounded to the west by a buried scarp coinciding, in places, with the mapped trace of the Superstition Hills and Superstition Mountain faults and the Imperial Fault. Where as on the other side of the trough, ie, the east side, they found thinning of the sedimentary section to be more gradual, no strong evidence of a buried scarp, and low seismicity. Thus they concluded that the present day rifting is occurring in the central and western portions of the buried rift valley.

In the 1973 and 1974 the author along with others (Woodward-McNeill, 1974) was involved in an extensive study of the faulting and tectonics along the eastern side of the Salton Trough for the possible construction of a power plant to be located south of Yuma, Arizona. One of the main purposes of this study was to investigate the possibility that the San Andreas Fault might extend to the southeast along the postulated Sand Hills faults and join with the Algodones Fault in southwestern Arizona near the proposed power plant site.

The investigation of the southern extension of the San Andreas consisted of reviewing research and studies by others, as discussed above, stereoscopic examination of several aerial photo flights along the postulated Sand Hills faults, examination of deep seismic reflection lines run by Exxon across the Sand Hills, and surface reconnaissance and limited geologic trenching across some of the photo lineaments suspected of being fault traces.

The aerial photo analysis found no surficial evidence of a recent fault trace or a suspected fault lineament along the east side of the Sand Hills. There was a strong linearity along portions of the western side of the Sand Hills which could represent possible fault control of the sand accumulation on this western side. The photos also revealed a series of en echelon lineaments on East Mesa west of the Sand Hills believed to be faults. These lineaments were examined and trenched in the field and confirmed to be faults. They were found to be primarily normal, down-to-the-west faults with possibly some lateral displacement, see Heath, 1980. These faults, here referred to as the East Mesa Faults, are believed to be basin edge faults, possibly normal listric faults, caused by either continued basin settlement or by compaction of the deep sediments in the trough or a combination of both. They may be similar in origin to the growth faults of the gulf coast region. The apparent laterally offset sedimentary facies observed in several trenches and the generally left stepping, en echelon fault pattern observed on the aerial photos suggest that these faults may also experience some lateral wrenching due to the active rifting within the Salton Trough.

Examination of the reflection seismic lines run across the Sand Hills by Exxon showed them to be of rather poor quality, due to the absence of good reflectors in the sedimentary section, but also showed some evidence of deep faulting along the trend of the Sand Hills.

The Algodones Fault was investigated to determine its characteristics and to assess whether or not it might extend northwest toward the postulated Sand Hills faults. The Algodones Fault was investigated with aerial photo analysis, geophysical profiles and seismic lines, extensive surface trenching, and hydrogeologic studies. It was found to be an eastwardly dipping, normal fault confined to the western margin of the Fortuna Basin in Arizona. There was no evidence that it crossed the Yuma basement high nor that it extended northward in to California, or connected in any way with the postulated Sand Hills faults. Six Exxon deep seismic reflection lines run across the area south of Yuma confirmed several basin edge, down-to-the-east, faults in the vicinity of the Algodones Fault and also several basin edge, down-to-the-west faults west of the Yuma basement high. We believe that is later series of faults represent faulting along the eastern edge of the Salton Trough and may be closely related to the East Mesa Faults described above.

One of the conclusions of this power plant study was that there was good evidence that the San Andreas Fault dies out in a spreading center at the south end of the Salton Sea and that it does not connect or extend into the area of the Sand Hills and that neither it nor the postulated Sand Hills faults connect with the Algodones Fault.

More recent studies by others tend to confirm the San Andreas - Salton Trough tectonics as discussed above. Dr. Kerry Sieh, who has been studying the San Andreas fault for the past two decades discusses the behavior of the southern section of the San Andreas Fault during the past 300 years, Sieh and William, 1990, and states that this southern segment is 200 kilometers long, extending from Cajon Pass to where it terminates just south of Bertram (Bombay Beach Area) east of the Salton Sea. On his Figure 1, also Figure 1 attached, he shows the Brawley Seismic Zone as an active step over to the west to join the north end of the Imperial Fault as earlier proposed by Kovach and others, 1962, Elders and Others, 1972, and Crowell and Sylvesters 1979. Dr. Sieh estimates that the last great earthquake on this southern segment of the San Andreas occurred in about 1676±35, or about 315 years ago. He estimates that this segment produces a very large earthquake every two to three hundred years and that it has accumulated enough strain since the last major earthquake to produce another large earthquake. The South end of this segment is approximately 45 miles northwest of the proposed landfill site.

The Brawley Seismic Zone was first defined by Johnson and Hill, 1982, where they analyzed aftershocks and earthquake swarms following the 1979 Imperial Valley Earthquake. They show the seismicity stepping over from the north end of the Imperial Fault towards the south end of the San Andreas Fault. They relate this seismic zone to active spreading centers as proposed by Elders and Others, 1972.

The Seismicity Map of California compiled by Goter, 1988, for the National Earthquake Information Center covering the year from 1808 to 1987, shows the same seismicity trend along the Brawley Seismic Zone.

Larsen and Reilinger, 1992, reviewed the new global positioning system measurements of strain accumulation across the Imperial Valley and conclude that the strain is accommondated exclusively along the Imperial Fault in the southern half of the valley and along several structures such as the San Andreas, Superstition Hills and the San Jacinto Faults to the north.

The National Earthquake Prediction Evaluation Council (NEPEC) in conjunction with the U.S. Geological Survey produced Open-File Report 88-398 (1988) where in it provides "Probabilities of Large Earthquakes Occurring on the San Andreas Fault". In this report they define the southern segment of the San Andreas to extend for 100 km from San Gorgonio Pass to where it terminates just south of Salt Creek on the east side of the Salton Sea. They calculate the probability of the next large earthquake to occur on this segment during the next 30 years to be about 40%. They further estimate that such a large earthquake could have a magnitude as large as M=71/2.

With regard to the postulated Sand Hills faults the latest State of California fault maps show alternate interpretations and also different interpretations from the earlier state maps which showed the Sand Hills faults dotted along both side of the Sand Hills. The new Preliminary Fault Activity Map of California, C.D.M.G., 1992-3, shows only one question marked fault along the eastern edge of the Sand Hills. The fault is shown as dotted and queried indicating that it is not seen at the surface and that its location and even existence is questionable. On the west side the map shows only the East Mesa series of en echelon faults mapped by Heath, 1980, as discussed above. It shows no west side Sand Hills fault as shown on earlier state maps.

The new C.D.M.G., 1992-1, Map of California showing "Peak Acceleration from Maximum Credible Earthquakes in California", provides estimates of the maximum credible earthquakes for faults considered active in California. The map does not show, nor do they assign an earthquake to any Sand Hill faults. They also do not show the East Mesa Faults on this map. They show a fault, nearby to the west, paralleling the ancient shoreline of Lake Cahuilla which they name the East Highline Canal Lineament, (See Figure 1 attached).

It appears that they consider this lineament to represent the potential seismicity along the eastern margin of the Imperial Valley, however, they do not define why they consider this lineament an active fault. For their earthquake analysis of this portion of the Imperial Valley they assign a maximum credible earthquake (MCE) of Magnitude M=61/2 to this lineament. They also assign MCEs to the Brawley Seismic Zone of M=6, the Imperial Fault of M=7, and the Southern Segment of the San Andreas Fault of M=71/2. They also assign an M=71/4 earthquake to the Algodones Fault but as discussed earlier this fault is confined to the Fortuna Basis in Arizona and does not enter California.

An overflight of the Sand Hills and East Mesa was conducted as part of this current review on Dec. 22, 1992. This over flight confirmed the existence of the East Mesa Fault as being easily recognized from the air. It also confirmed some lineaments along portions of the west side of the Sand Hills which could possibly represent faulting or fault control of the sand depostis. It is also possible that these lineaments are simply wind controlled longitudinal sand ridges. No ground examination or geologic trenching has been done in this area to confirm faulting. During the overflight the eastern side of the Sand Hills was also examined and no evidence of faulting or fault related types of lineaments could be observed.

Conclusions

Based on my review of research and mapping of others, many of whom are respected leaders in their field of seismology, geophysics, and seismic geology, and my own studies in the area, I have drawn the following conclusions as to the regional tectonics, active faulting and seismic hazard of the Imperial Valley as it relates to the proposed landfill site.

- The Salton Trough is in a transition zone where crustal rifting processes have interacted with transform faulting and spreading centers to form a series of interconnected pull-apart basins. That it is a deep sedimentary filled basin and that the deepest portion coincides with the zone of highest seismicity. That the zone of present day rifting coincides with known faults along the center and western portions of the Trough, the Brawley Seismic Zone and the southern segment of the San Andreas Fault.

- The San Andreas Fault terminates at the southern end of the Salton Sea in a spreading center where the rifting steps over through the Brawley Seismic Zone to the Imperial Fault.

- There is little evidence that the postulated Sand Hills faults exist on either side of the Sand Hills as previously mapped. There is no surface evidence of faulting along the east side of the Sand Hills and only the linearity of sand ridges on the west side to suggest faulting. However, seismic reflection lines suggest possible faulting under or adjacent to the sand hills.

- The en echelon series of East Mesa Faults appear to represent the active eastern margin of the trough. They appear to be down-to-the-basin, normal listric faults do either to continued basin settlement or compaction of basin sediments. They could be aseismic or could produce moderate size earthquakes. They are not believed to be connected with the San Andreas Fault and are not believed to be capable of producing large earthquakes similar to those of the San Andreas Fault Zone.

- Because we cannot preclude the possible existence of other trough or basin edge faults underneath the San Hills it is not possible to completely eliminate them from seismic consideration for the site. There appear to be three possible locations for one or more of these basin edge faults, ie, the hypothesized East Highline Canal Lineament, the East Mesa Faults or the postulated Sand Hills faults. Based on the prior studies and the recent overflight we believe that if there is an active Sand Hills fault it would most likely lie along the western edge of the Sand Hills and i fact may well be represented by the young and apparently active East Mesa Faults. Because of these uncertainties the conservative earthquake scenario for the site would be to place a design earthquake on the eastern portion of the East Mesa Faults or nearby along the western edge of the Sand Hills. Such a western edge Sand Hills fault would lie approximately 9 miles west of the site at its closest approach.

- In selecting a maximum credible earthquake (MCE) for this trough edge system the one selected by the state, C.D.M.G., 1992-1, for the East Highline Canal Lineament may be appropriate, ie, MCE=61/2. The same state report assigns MCEs to other faults in the Imperial Valley that should be considered for the seismic hazard to the site. These are: San Andreas Fault, Southern Segment, M=71/2; Brawley Seismic Zone, M=6; Imperial Fault, M=7; and Superstition Hills Fault, M=7.

- The question of whether the East Mesa Faults or a postulated Sand Hill faults are connected with the San Andreas Fault and whether a large earthquake on that fault could cause sympathetic rupture on one of them should also be considered in the seismic analysis. Because it is widely accepted in the geologic and seismic community that the San Andreas Fault ends near Bertram (Bombay Beach Area) and the active tectonics step over through the Brawley Seismic Zone to the Imperial Fault, there is little likelihood that a major southward extension of a San Andreas rupture into the Sand Hills area would occur. However, a major event on the San Andreas might cause or trigger sympathetic movement on one of the trough edge faults. It is also believed that such an event would produce no higher a maximum earthquake on one these faults then has already been estimated. The seismic shaking at the site, as measured by peak ground accelerations would be expected to be no more than for individual MCEs on each fault as presented above.

Respectfully Submitted:

Edward G Heath

Edward G. Heath
Consulting Engineering Geologist, CEG915

cc: Marshall Payne

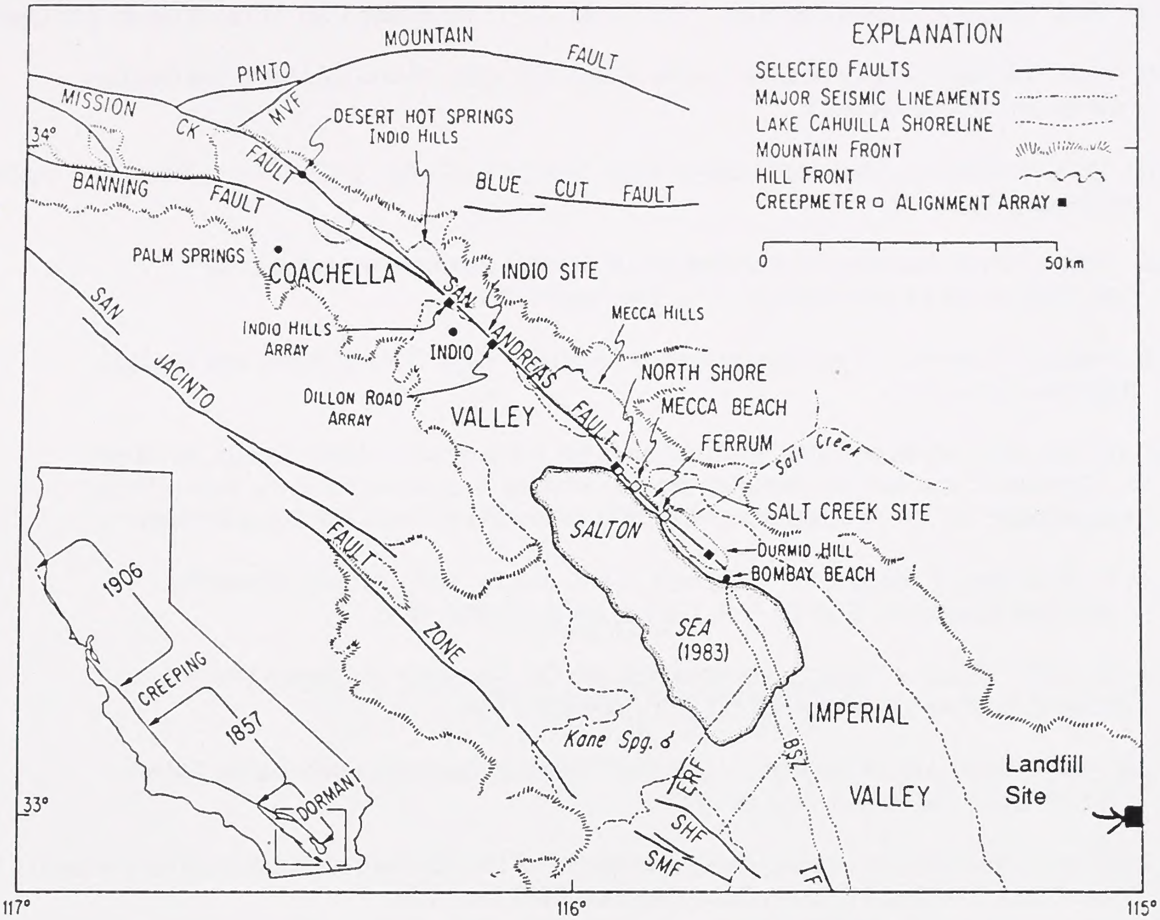

Figure 1 Tectonic setting of the southernmost San Andreas Fault from Sieh and Williams, 1990.
Note: San Andreas Fault, Brawly Seismic Zone, BSZ, and Lake Cahuilla Shoreline.

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APPENDIX E

SOIL PROFILE MEASUREMENTS FROM CONFIRMATION SOIL TEST PITS

TABLE E-1

SOIL PROFILE MEASUREMENTS FROM CONFIRMATION SOIL TEST PITS(1)(2)(3)

STATION	SOIL HORIZON THICKNESS (inches)			
	AV-B1	B2tk	B3-C1	C2
1	0 to 2	2 to 12	12 to 18+	--
2	0 to 2	2 to 24	24 to 48	48 to 96+
3	0 to 1.5	1.5 to 18+	--	--
4	0 to 2.5	2.5 to 3.0	30 to 48	48 to 56+
5	0 to 1.5	1.5 to 1.0	10 to 14+	--
6	0 to 1.5	1.5 to 7	7 to 16+	--
7	0 to 1.5	1.5 to 6.5	6.5 to 16	16 to 48+
8	0 to 4	4 to 11	11 to 18+	--
9	0 to 2.5	2.5 to 9	9 to 14+	--
10	0 to 2	2 to 10	10 to 18+	--
11	0 to 1.5	1.5 to 9	9 to 13.5+	--
12	0 to 1	1 to 12	12 to 16+	--
13	0 to 1	1 to 12	12 to 14+	--
14	0 to 1	1 to 12+	--	--
15	0 to 1.5	1.5 to 10	10 to 12+	--

91-296 (3/11/93/ds)

NOTES:

(1) Location of test pits shown in Plate I.
(2) All test pits were excavated on piedmont fan surfaces at least 35,000 to 40,000 years old.
(3) Criteria used to distinguish soil horizons after Shlemon, 1993.

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